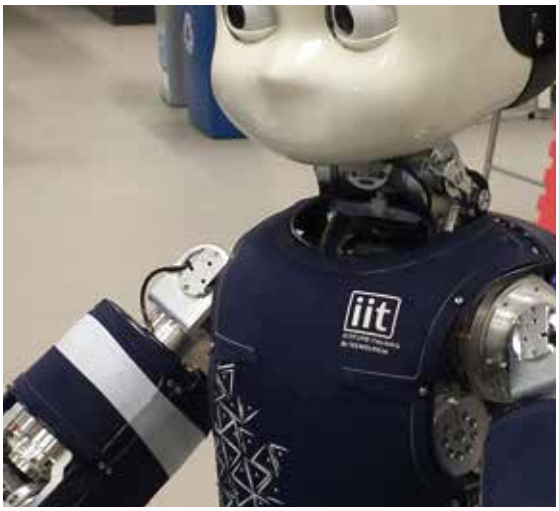
SKILLS AND EDUCATION FOR ROBOTICS AND AI

(SERAI)



A report for

SHEFFIELD ROBOTICS

The University Of Sheffield.

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This section will examine some skills initiatives at Sheffield University and in the city and beyond and explore what key stakeholders at the university see as their role in upskilling the British workforce in readiness of Industry 4.0.

SKILLS AND EDUCATION FOR ROBOTICS AND AI (SERAI)

J.M.Keynes:
"The reason why human labour has prevailed relates to its ability to adopt and acquire new skills by means of education".

Marie Curie:
"Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less".

Part 1 THE ISSUE

Introduction

'We are at one of the most important, exciting and challenging times in the history of global enterprise[1], according to Secretary of State for Business, Energy and Industrial Strategy, The Rt Honourable Greg Clark, in the opening words of his recent Industrial Strategy White Paper Building a Britain Fit for the Future. What enables the exciting industrial and commercial future that the White Paper anticipates are technologies such as robotics and AI that are currently revolutionising the global economy and society. 'Britain', the Secretary of State goes on to say, 'is extraordinarily well-placed to benefit from this new industrial revolution' and that 'the earliest adopters of new technologies are able to reap the greatest rewards in terms of additional jobs and increased revenue[2].

The industrial revolution that he cites has become widely known as Industry 4.0, or the fourth Industrial Revolution; the former three being those powered by steam, electricity and computing. Originally coined by the economist and engineer Klaus Schwab, the fourth industrial revolution is characterised by a blurring of the physical and technological worlds, powered as it is by robotics, AI, the Internet of Things, cloud computing and additive manufacturing. Furthermore, as Siemens CEO Professor Juergen Maier highlights in the Made Smarter Review, although 'emerging technology breakthroughs in fields such as AI, robotics, and the Internet of Things are significant in their own right … it is the convergence of these IDTs that really turbo-charges their impact.[3] As with the previous industrial revolutions, the influence of such a powerful congruence of new technologies on industry, society and the economy are both hugely disruptive and potentially highly progressive.

The analogous linking of Industry 4.0 with the previous three industrial revolutions that shaped, disrupted and developed the world's economy and society over the last two hundred and fifty years, is far from specious. As George Graetz and Guy Michaels reported in their 2015 paper Robots at Work for the CEP, robot densification across the major industrialised nations between 1993 and 2007 raised GDP and labour productivity by 0.37 and 0.36% respectively, a figure 'fairly comparable to the estimated total contribution of steam technology to British annual labour productivity growth[4].

According to the 2016 Citi GPS report with the Oxford Martin School, over 96% of institutional clients who participated in Citi's survey on technology and work 'believe that automation will accelerate over the next five years relative to the previous five years[5]. As director of the Oxford Martin School, Ian Goldin, and Citi's Global Head of Research Andrew Pitt, comment in their foreword to the reportsuch 'technological dynamism will remain the best way to maximize employment and to benefit positively from new technologies[6]. To attempt to assign some figures to the potential benefits of answering the Secretary of State's call for early adoption of the new technologies powering Industry 4.0, 'the work undertaken for the Made Smarter Review found that the positive impact of faster innovation and adoption of IDTs could be as much as £455 billion for UK manufacturing over the next decade[7], increasing manufacturing sector growth between 1.5 and 3 percent per annum[8], creating a conservative estimated net gain of 175,000 jobs throughout the economy.[9] Overall, from the data and evidence collated, we are confident that industrial productivity can be improved by more than 25 percent by 2025.[10]

In October 2017, Fellow of the Royal Society Professor Dame Wendy Hall and the VP of AI at Facebook Jerome Pesenti published their much-anticipated review into how to grow the Artificial Intelligence industry in the UK, the country where Alan Turing is widely regarded as having launched and inspired much of the development of AI just after the Second World War. The authors opened their executive summary with the promise that 'increased use of Artificial Intelligence (AI) can bring major social and economic benefits to the UK. With AI, computers can analyse and learn from information at higher accuracy and speed than humans can. AI offers massive gains in efficiency and performance to most or all industry sectors, from drug discovery to logistics. AI is software that can be integrated into existing processes, improving them, scaling them, and reducing their costs, by making or suggesting more accurate decisions through better use of information. It has been estimated that AI could add an additional USD $814 billion (£630bn) to the UK economy by 2035, increasing the annual growth rate of GVA from 2.5 to 3.9%. [11] Our vision is for the UK to become the best place in the world for businesses developing and deploying AI to start, grow and thrive, and to realise all the benefits the technology offers.[12]

In the words of the Secretary of State for Business: 'to benefit from the opportunities before us, we need to prepare to seize them.[13] The Secretary of State develops the argument further, stating that 'as with previous revolutionary technologies, these changes cannot be resisted and it would be

irresponsible to fail to prepare. Meeting our Grand Challenge means maximising the opportunities created by AI and advanced data technologies and responding to the potential impacts on society.[14] Or to put it another way - as voiced by Siemens CEO and author of the Made Smarter Review Professor Juergen Maier - 'we haven't reached our full potential and have left too many of the opportunities arising from the Third Industrial Revolution to other nations.[15]

Skills

The key to enabling the UK to seize and maximise the opportunities generated by the Fourth Industrial Revolution, as director-general of the CBI Carolyn Fairbairn recently wrote, is skills training and education. "Investing in all our skills is at the heart of building an economy that is fit for the future. Skills are vital to competing globally - and seizing the opportunities of the fourth Industrial Revolution".[16]

As Goldin and Katz observed of the industrial revolutions of the twentieth century - that it was a 'race between education and technology[17] - so the Fourth Industrial Revolution of the 21st century 'will have extraordinary implications on the range of skills that today's young people will require in every aspect of their lives' since 'data and digital technologies promise revolutionary transformational changes across the full range of industry sectors and spheres of life'.[18]

When recently presenting evidence to the House of Commons Science and Technology Select Committee Inquiry into Robotics and Artificial Intelligence, a representative of vanguard AI think tank DeepMind stated that "one of the most important steps we must take is [ensuring] that current and future workforces are sufficiently skilled and well-versed in digital skills and technologies, particularly STEM subjects.[19]

The various responses to the initial green paper Building Our Industrial Strategy, on which the Secretary of State's Industrial Strategy White Paper was based, repeatedly stress the need for the UK to concentrate on skills and education in preparing the workforce of now and the future for the challenges that Industry 4.0 will bring. The Royal Society sets the tone, opening its response with the words that 'The Society welcomes the emphasis on science and skills within the Green Paper.[20]

In its response, Nesta follows The Royal Society in welcoming 'the long overdue recognition that skills development is as important to growth as infrastructure, investment and trade[21]. Nesta calls for increased investment in technical and STEM skills education, pointing out however that 'this investment needs to be in the context of a strategy that should be looking at not just industries but jobs and skills for the future'. Nesta concludes by stressing again that 'the government should continue to support skills development throughout the talent pipeline, to ensure that workers have the skills they need to thrive in a labour market that will be increasingly influenced by technological advances and automation.' While Universities UK cites a recent CBI report in its response to the green paper that 'the primary factor in boosting regional productivity is educational attainment and skill levels.[22]

How alarming then that a survey by the UK charity Go.On.UK, and cited in the Made Smarter Review, recently found that in Britain 'over 12 million people and a million small businesses do not have the skills to prosper in the digital era.[23]

The UK currently ranks just 18th in the world in 'skill levels' leading to success or failure to thrive in Industry 4.0' according to a recent UBS White Paper for the World Economic Forum.[24] Britain lags behind Singapore, Finland, the Netherlands, Switzerland, Belgium, the US, Norway, Australia, Denmark, New Zealand, Sweden, Hong Kong, Taiwan, Ireland, Austria, and Germany; the vast majority of our major industrial competitors. Britain is only 12th in the same study in 'education allows adaptive skills', in other words if the education system produces workers who can adapt to the kind of rapidly evolving technologies and working practices inherent in Industry 4.0.

Britain performs well at the highest academic and professional levels – with three universities in the top ten for STEM according to higher education advisor Quacquarelli Symonds (QS) and 5th in the world in Scientific American's scorecard of 'Best Countries in Science'[25], but it is mainly the low levels of more basic STEM skills in the wider population that account for its position below most of its competitors in terms of skills leading to a country thriving in industry 4.0.

The British Academy cites a Tech Partnership Survey in 2015, whose results 'showed that a general shortfall in the skills of employees is holding back one in two firms in the technology sector, with a consequent knock-on impact on economic growth as technology is not harnessed as effectively as it could be.'[26]

BEIS' Made Smarter Review highlights the digital skills deficit as the 'greatest barrier to IDT adoption'. The Review's projections make similarly gloomy reading: 'there is already an identified shortage of digital skills in the UK economy, and the demand for these skills is projected to increase. It has been predicted that, within 20 years, 90 percent of all jobs will require digital skills. This means that approximately 16.5 million people in the UK are going to need to be skilled to become 'digital workers' and 'digital makers'.

'Yet, there are 10.5 million people currently lacking basic online skills, the majority of whom are aged over 55, and many of whom are working in sectors where digitalisation will be crucial to keep the UK competitive internationally. The pace of change unleashed by digitalisation means that around two-thirds of children in primary school today will work in jobs which do not even exist yet. The nature of employment is also continuing to change. The days of working for a single employer have ended. Individuals will have a number of careers over their working lives and will need to continually reskill to be relevant in the marketplace. There is a need to develop a culture of lifelong learning and reskilling, such as the Singapore "skills future program". And there is a need to improve visible career pathways for adults, such as those in the US (Van Horne et al 2015).'

'While young people will acquire basic digital skills by default because of digital's pervasive nature, to be truly employable more advanced skills are required. Digitalisation will offer real benefits to older workers and to the sectors where there are larger concentrations of such workers. This group must acquire basic and then more advanced digital skills specific to their sector and nature of work in order to remain employable as technology advances. And, because around two-thirds (65 percent) of the workforce of 2030 has already left the education system, the UK cannot rely on the education system to satisfy industry's demand for digital skills in the short to medium term. In an industrial sector which employs around three million workers, this means that two million people will potentially need to be upskilled or reskilled in the workplace.'[27]

In its 2016 review of potential economic growth in the UK in light of Industry 4.0, The ScaleUp Institute highlights the 'consistent, ongoing demand for STEM skills across all parts of the country and most industry sectors. 32% of UK firms have difficulties recruiting staff with skills in science, technology, engineering and mathematics.' The Institute concluded that '82% of scale-up leaders stated that access to people with the right skills was the biggest barrier preventing their growth'[28].

As Professor Dame Wendy Hall and Jérôme Pesenti point out in their influential paper on growing AI in the UK 'The more people who have the right foundational STEM skills, the more can train in the higher skills, but also more will be able to work in adjacent roles: working in and around AI rather than developing it at the most complex levels.'[29]

So it is not just high-level skills - the skills to build and design the robots of

the future and code and program AI and new forms of Machine Learning – but a wider range of STEM skills, basic proficiencies in the sciences, technology, engineering and maths that can serve as a bedrock of knowledge on which to build skills of the future and the more creative, problem-solving skills that workers of the future will need when working alongside intelligent machines if the UK is to truly thrive in Industry 4.0.

In its response to the initial government green paper Building Our Industrial Strategy, the authors of Nesta's paper highlight the remarkable statistic of 'one popular estimate[30] that 65 per cent of children entering primary school in 2016 will by the time they are economically active (in 15 or so years) work in completely new jobs that do not exist today. This makes it all the more important that we set learning priorities for young people today that are grounded in a rigorous assessment of what skills will be required of them when they enter the workforce.'[31].

As Professor Hall and Jérôme Pesenti put it in terms of what is needed to grow the Artificial Intelligence industry in the UK: 'AI can be applied in a wide variety of industry sectors and application areas, and that range is only going to grow. This means that there is growing demand for professionals who are not core specialists in AI but will be needed to successfully add AI into functions in those sectors. There will be a need for support skills for AI across: - data preparation, curation, protection, explaining AI functions to staff and customers, managing reporting, accountability, [and] liability.'[32]

A paper on requisite digital skills for the UK economy by Ecorys UK advises the government that 'there will be a need for professionals who can use AI tools successfully in specific domain areas, including: research scientists, maintenance technicians, surgical technicians and healthcare professionals working with assistive technology, mechanical engineers in manufacturing and transport; and "applying AI" roles in service sectors – insurance, advertising, design, creative, retail, entertainment, financial. There have been several reports in recent years that developed and evidenced the case for improving education and training in maths, computing, data science, and the full range of digital skills.[33]

Computer Science Education

The Royal Society opens its highly influential 2017 report After the Reboot – Computing Education in UK Schools by similarly highlighting the 'revolutionary transformational changes' that the 'unprecedented digital revolution' is bringing to a 'range of industry sectors and spheres of life'; stressing that 'it will have extraordinary implications on the range of skills that today's young people will require in every aspect of their lives.'[34]

The Royal Society's report follows the calls of academia and industry cited above concerning skills provision in the UK that 'computing education must enable young people to continue to keep up with the pace of technological change' if we are to safeguard 'the education of future generations and our economic prosperity as a nation.'[35] What the Royal Society found, however, was that 'computing education across the UK is patchy and fragile', with insufficient time given to computing lessons in the curriculum and 'a majority of teachers … teaching an unfamiliar school subject without adequate support'.[36] In a survey especially commissioned for the report, The Royal Society found that '44% of secondary school teachers only felt confident teaching the earlier stages of the curriculum where there is less of a computer science focus.' Not only that but '26% of the secondary school teachers we surveyed indicated that they had not undertaken any computing-related professional development activities in the past year', giving them little chance to gain the confidence in teaching computing that many lack. The problem is exacerbated by the fact that schools are finding it increasingly difficult to attract new teachers to computing, with England meeting only 68% of its recruitment target from 2012 to 2017.[37]

Dave Gibbs, the Computing and Technology Specialist for STEM Learning UK, feels that the main reason that barely half of the computer science teachers surveyed by the Royal Society feel comfortable teaching the computing components of the curriculum is that most computing teachers lack a specialist computing background, and so find the content of the GCSE course hard to comprehend, let alone being able to teach it to others. Many teachers now teaching computing were not educated as computer scientists but come from a background in ICT or DT; in Mr Gibbs' words 'they were competent in using computers but didn't necessarily know anything about them, like a competent driver being asked to open a garage and start fixing cars.'[38]

'With not only schools, but also the British Computing Society's own teaching scholarship scheme failing to reach its recruitment

targets, the number of schools able to offer the GCSE is plateauing to a level where nowhere near as many schools are offering a GCSE in computing as used to offer ICT', Mr Gibbs comments, adding that 'what we're in danger of is ending up with is a smaller number of young people with a better knowledge of computer science and a lot of young people who haven't really had an education in computer science from ages 14-16 … it could end up like electronics in schools: a niche group of teachers teaching a niche group of students'[39]

As Professor Hall and Mr Pesenti put it: 'the addition of computer science to the National Curriculum is an excellent step but will only deliver fully if there are enough teachers who can teach it well. The British Computer Society has expressed concern that not enough students are taking up computer science and suggested that as many as 70% of secondary school computer science teachers could be lacking a relevant computer science background to teach at GCSE level. Therefore, more and better teacher training in computer science would improve outcomes.'[40]

With no well-trodden path between taking a degree in computer science and joining the teaching profession, there has been a dearth of computing specialists teaching in schools, making CPD a vitally important route to attaining higher standards in computer education in schools, encourage school heads to push computing as an important GCSE option offered by the school and thus to grow the numbers of children studying computing. As the Royal Society reports in its review After the Reboot, 'only a disappointing 11% of all students take GCSE computer science.'[41] Trying to answer why the numbers of pupils taking computing as a GCSE is so low compared to the more mainstream STEM subject, Mr Gibbs feels that the Computer Science GCSE is a difficult examination and that although he welcomes a new government focus on technical education and other routes to obtaining meaningful qualifications, 'the landscape is still very confused' - school heads need their students to take qualifications recognised by the DfE yet are faced with 'a very narrow choice of qualifications that aren't GCSE that are engaging and interesting and can practically be taught in mixed classes.' Mr Gibbs believes that there could be more practical and outcome-driven components in computer science courses, using robotics for example as a vehicle to deliver programming and engage students more. Although Robotics and Artificial Intelligence are prime drivers of Industry 4.0, they don't feature significantly in the Computer Science syllabus and tend to 'fall in the gap between computing and DT'.[42]

Gender

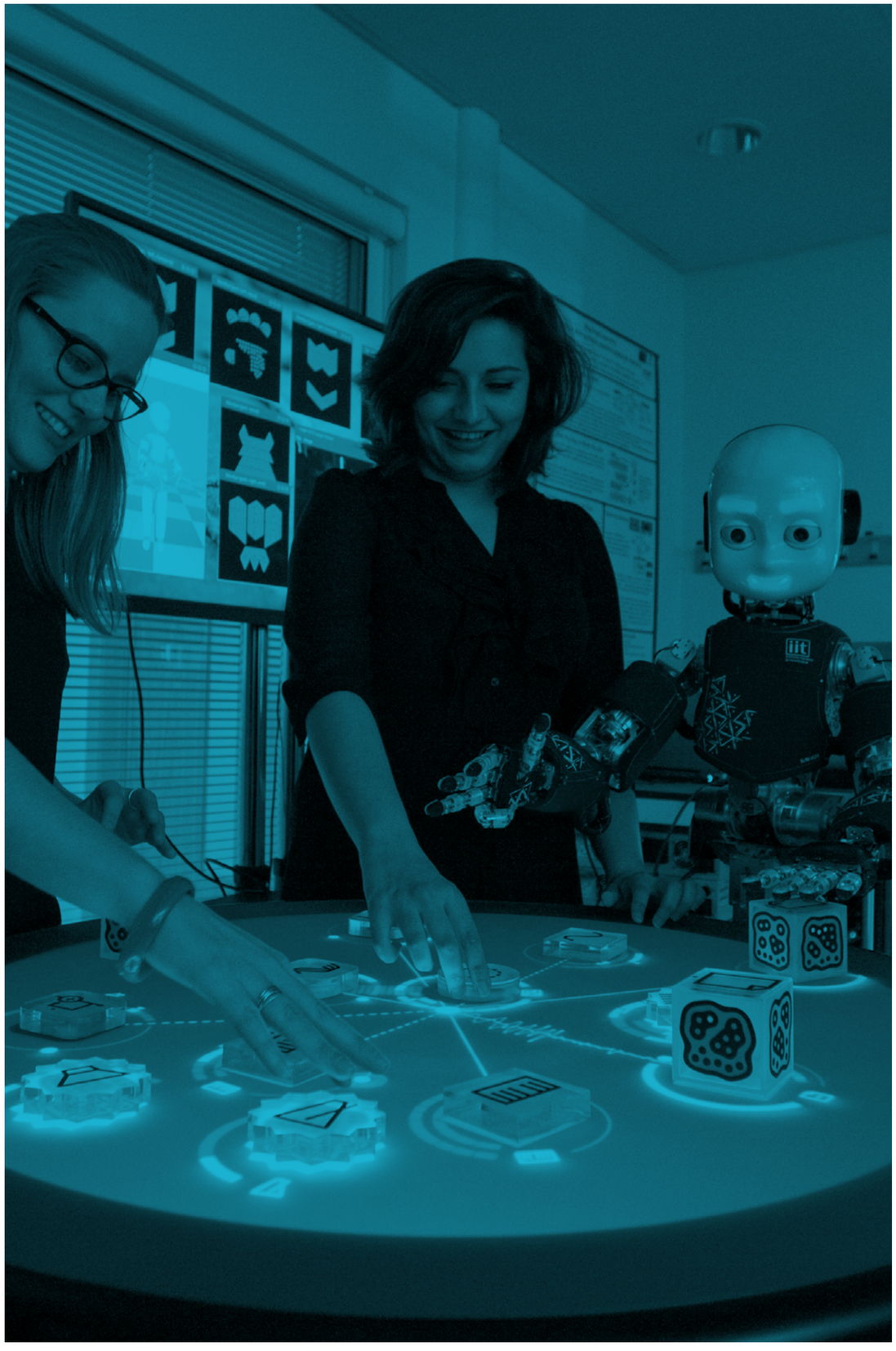
The very low uptake of computer science at GCSE level is not helped by the strong gender bias to computing in schools. As the authors of the Royal Society report comment – 'though many of the great pioneers of computing were women, across the UK computer science is an overwhelmingly male-dominated subject and

workforce. At GCSE, there is a 20% uptake from girls, while Scotland also had a 20% female uptake at National 5 in 2017. At A level, there is only a 9% uptake from girls, and this has not changed for many years.'[43]

It is not only a problem in computing. Although girls outperform boys at GCSE and A level in A-C grades in STEM subjects, a meagre 21% of the STEM workforce and only 15% of the ICT workforce are female. 9% of STEM apprenticeships are taken by women.[44] Responding to the Building Our Industrial Strategy green paper, the UK Women's Budget Group stressed that 'closing the gender gap in STEM is critical to addressing the skills shortage in STEM subjects. Women make up only 25% of those graduating from degrees in STEM subjects. The proportion in engineering is still lower (14%). This feeds through into the labour market where women make up only 21% of those working in STEM. In engineering the proportion of women is again particularly low (8%).[45]

Howard Baker, creator of the Micro:bit and the one million drop, in which Micro:bit computers were given away free to a million children starting secondary school, believes that the exclusion of women from STEM careers helps explain Britain's overall poor performance in skill levels and its position so low down the table of 'skills needed to thrive in Industry 4.0'. If there were more women in STEM, the overall skill figures would be much higher. He feels that Industry 4.0 is creating a new society and economy around itself and that the lack of women working in technology means that 'society is losing half its voice'. Mr Baker thinks that the dearth of female role models in STEM is key our failure to bring more women through into STEM careers. 'It's as if a whole gender needs permission to take part' he says. 'We have to make it socially acceptable for girls to be involved in STEM'[46].

Dr Gwendolen Reilly, Senior Lecturer in Bioengineering at Sheffield University and Faculty Director of Women in Engineering sees 'the fact that most STEM teachers at secondary school level are men is also problematic in attracting girls into STEM subjects and a STEM career. A lack of female role models in STEM careers adds to the problem'. Girls at school see male STEM teachers and male figures of authority in STEM occupations and feel that



science and technology isn't for them. If they are determined enough, Dr Reilly feels, to pursue a STEM education and career, 'they are often in a minority and are easily singled out, so that teachers and lecturers may not be treating them the same as men without even realising it. When they apply for jobs, it's the same thing; they might be the only woman applying – then they feel discriminated against or singled out again. It goes on and on'.[47] So much so that the UK has the lowest percentage of female engineering professionals in Europe, at less than 10%, while Latvia, Bulgaria and Cyprus, for example, lead with nearly 30%.[48]

Citing the Institute of Engineering and Technology's 2015 survey into gender ratios in engineering and technology, The Women's Budget Group's response to the BEIS Green Paper points out that 'some of the statistics highlighted in the IET's report have not changed significantly since 2005 … For example, the number of women in engineering has remained under 10 per cent of the total engineering workforce in the UK; the gender balance in the profession remains one of the worst in Europe."[49] The Group has some strong advice for the UK government: 'The continued issues of low productivity in the UK economy demonstrate the need for investment in education and training and we welcome the priority given to this in the Green Paper. We call for a system of life-long learning opportunities which would give women the opportunity to update existing skills or retrain. Action to address the gender gap in technical and STEM subjects is critical in order to address the skills shortage in STEM and should be reflected in education and training policy.'[50]

Adult Skills Training

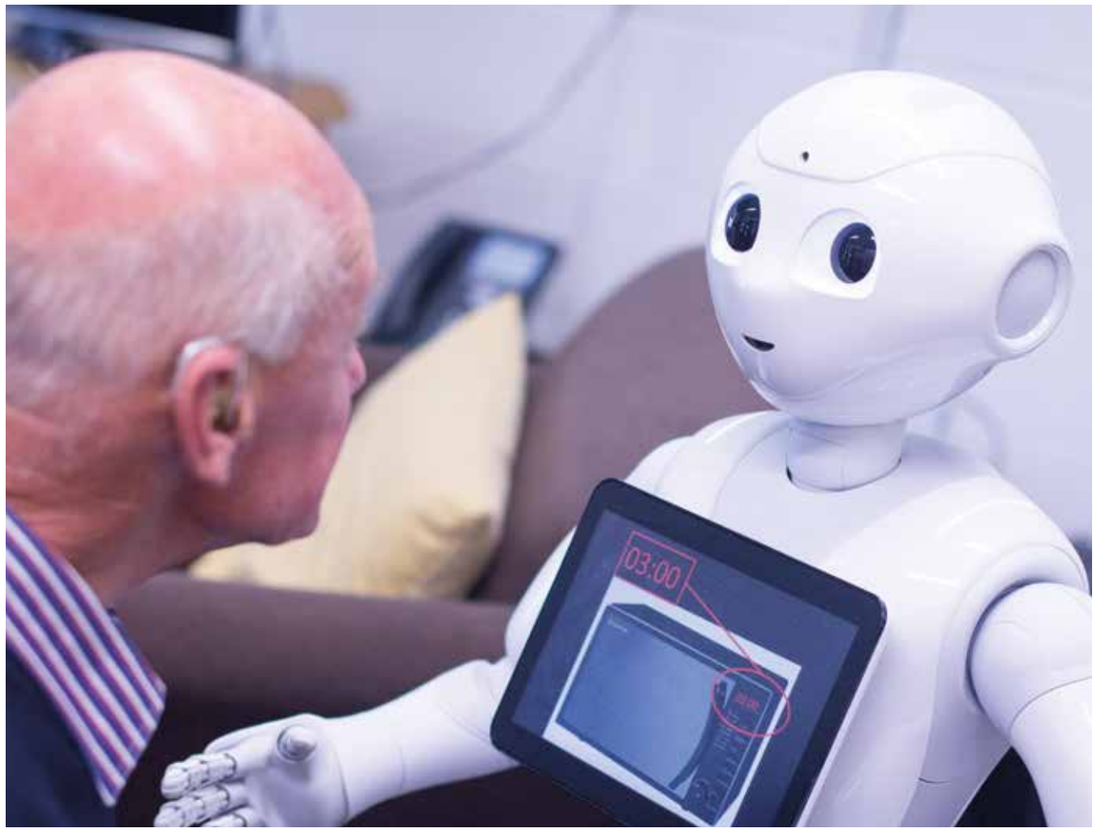
The Royal Society also stresses the need to reskill the current adult workforce as well as concentrating on improving STEM education at school level: 'Lifelong learning will also be important in a changing work environment and improvements in further education will be required to support an industrial strategy in which economic growth and support for working communities dovetail effectively with changing industrial practises linked to (for example) automation.'[51] Professor Julie Lydon, Chair of Universities Wales, makes a similar point in her paper The Robots are Coming: 'as well as providing education and training to young people just entering the labour market, it will become increasingly important to ensure that those already in the workforce are given the opportunity to upskill and retrain as the economy and the workplace enters a period of predicted rapid change.'[52]

As the authors of the Made Smarter Review point out: 'because around two-thirds of the workforce of 2030 has already left the education system, the UK cannot rely on the education system to satisfy industry's demand for digital skills in the short to medium term; this means that two million people will potentially need to be upskilled or reskilled in the workplace.[53]

Again, the UK Women's Budget Group offered strong advice to the Department of BEIS in its response to the Building our Industrial Strategy Green Paper: 'successive governments have failed to develop a training culture that accepts that high productivity and the good employment conditions required to produce it both need the development of skills, both by the state and by encouraging/requiring employers to train. This is not a sensible strategy for a relatively rich country such as the UK. It has led to British workers being less productive, paid less well and treated worse than those of currently much poorer countries.'[54]

Perhaps the UK Women's Budget Group's admonition was taken on board by the writers of the resultant Building a Britain Fit for the Future White Paper with the pledge that 'as technological change transforms the jobs and the skills that our businesses require, we need to make sure that people have the opportunity to learn and train throughout their working lives. At the moment, our problem is not unemployment caused by technology, it is low earning power caused by, among other reasons, a failure to use technology. Through our Industrial Strategy, we are determined to ensure that we have both the skills to take advantage of new technologies and the means to help those who are affected by technological change'.[55]

The authors of the Made Smarter Review certainly concur with the need to provide businesses with the requisite skills for them to flourish in Industry 4.0 but would concentrate their efforts on SMEs since '99.4 percent of UK companies are SMEs, with limited capacity and capability to adopt digital technology. Industrial SMEs frequently lack the information, expertise and skills, training, resources, strategy and, moreover, the confidence to adopt new technologies.



Our review has set an ambitious goal to reskill and upskill a million workers over the next five years. Its focus, although not exclusively, will be on SME workers (who represent a third of industrial sector employees) through the better coordination of IDT-related skills initiatives and institutions.'[56]

Further Education

As the executive summary of the World Economic forums recent White Paper on Accelerating Workforce Reskilling for the Fourth Industrial Revolution points out: 'Continuous learning lies at the heart of thriving in the context of the Fourth Industrial Revolution. The skills required for most jobs are evolving rapidly but our adult education and training systems are lagging behind. While 35% of the skills demanded for jobs across industries will change by 2020, at least 1 in 4 workers in OECD countries is already reporting a skills mismatch with regards to the skills demanded by their current jobs. Thus, enabling and empowering workers to transform and update their skills is a key concern for businesses and societies across the globe.'[57]

If the UK is to pursue the goal laid out in The Made Smarter Review to reskill and upskill a million workers in order to give manufacturing the skill base that it requires to thrive in Industry 4.0, the UK will need a robust system of adult education and culture of lifelong learning, or of 'continuous learning' as the WEFO White Paper terms it.

'Lifelong adult education and training is a core part of a successful Industrial Strategy and a precondition to its success', says The Association of Colleges in its response to the government's industrial strategy Green Paper. 'Action to support adult skills provision in England will raise productivity, help those who are unemployed or on low wages, and ultimately strengthen the country's economy following our departure from the European Union (EU). To do this, the UK needs long-term investment and reform to improve the availability of skilled and highly-qualified people. Economic success in the coming years will depend on embedding a lifelong learning culture throughout our society. Adults with low and medium skills need to be encouraged and supported to take up learning opportunities throughout their working lives and fill gaps in their basic skills, retrain or upskill.'[58]

Yet, according to government figures, there are 1.5 million fewer adults participating in further education than there were ten years ago. Such is the current crisis in the funding of further education that 'the number of adult learners fell by 10.8 per cent in just a single year between 2014 and 2015'.[59] 'Spending on core adult skills fell by 40% in England between 2010/11 and 2015/16, taking inflation into account.'[60]

David Hughes, chief executive of the Association of Colleges, writes that: "Further education has been starved of the investment needed to support young people and adults gain the skills they need for successful careers. Without new investment now, we will see more employers failing to fill skilled jobs.'[61]

So if the funding crisis in further education colleges renders them unable to provide the skills training requisite for the UK to meet its goals in being at the forefront of the robotics and AI industrial revolution, is it down to businesses themselves? Not according to Stephane Kasriel, CEO of Upwork: 'Companies need to look beyond the "not my problem" mentality when it comes to skills acquisition. If nobody takes responsibility for training, simply assuming that some other party (another company, universities, the government) will take care of it, then we have a classic tragedy of the commons. Instead, we all need to contribute to investing in workers' skills.'

'To facilitate this kind of cooperation, there is a big role for public-private partnerships, such as internship and apprenticeship programmes, and vocational training that prepares young people for jobs that don't necessarily require a college degree, but for which industries have specific skills needs. This model has produced great success in other countries, such as Germany and Switzerland. Both of these countries have demonstrated strong outcomes in procuring adult technical skills and their models could be expanded to other countries.'[62]

The World Economic Forum's White Paper sees an opportunity for us to rethink adult education and ways to provide workers with the skills that they will need: 'Growing awareness of technological changes associated with the Fourth Industrial Revolution creates a new window of opportunity for concerted action for investing in the skills and potential of the workforce of the future at all ages. A new deal for lifelong learning is needed globally to provide dynamic and inclusive lifelong learning systems, to resolve both the immediate challenge and to create sustainable models for the future. Given the right balance, a dynamic training ecosystem has the potential to provide deeply fulfilling careers to future workers while enhancing social cohesion and equity. Policymakers, business leaders and other stakeholders need to work together to ensure that adult training and education systems optimize the availability and competence of the labour force, while providing educational opportunities for the entire adult population. This requires multistakeholder collaboration and investment in developing robust and dynamic adult training and education systems.'[63]

Robotics and Future Employment

Although some newspaper headlines over the last year or so are not to be taken too seriously – such as that in the Daily Star on the 4th March 2018: 'Robot suicide WARNING: Humans to 'kill themselves' in jobless AI HELL', we have nevertheless seen a barrage of negative media publicity for robotics and AI. Some - such as the following headline from the Telegraph – 'Killer robots will leave humans 'utterly defenceless' warns professor'[64] are concerned with a supposed human fear of robots, or of AI: 'Robot WARNING: AI to 'replace human mind' as machines take over economy'[65] - and are often fuelled by youtube views in the multi-millions of new sub-military-seeming humanoid robots developed by Boston Dynamics, such as 'Handle' featured in the Guardian last year: 'Boston Dynamics unveils 'nightmare-inducing' hybrid robot' or 'Atlas', whose youtube video has been watched twenty eight million times.[66]

Mostly, however, the headlines concern supposed enforced mass unemployment caused by robots and AI taking human jobs, such as the relatively sober headline from the Guardian last year: 'Robots will destroy our jobs – and we're not ready for it'[67], or with a little more hyperbole from BBC online: 'Robot automation will 'take 800 million jobs by 2030'[68]; or the Daily Mail's regional analysis: 'Is YOUR town at risk from robots? Map of Britain reveals the areas where jobs are most at risk from automation as experts warn the 'unprecedented change' could wipe out a third of roles'[69]; or the more urgent 'AI FEARS: New laws DEMANDED over concerns at speed of super robots taking over our jobs'[70] from the Daily Express last year, or even 'Robot WARNING: AI to 'replace human mind' as machines TAKE OVER economy'.[71]

The recent Deloitte report Talent for Survival: Essential skills for Humans Working in the Machine Age[72], written with the economist Carl Benedikt Frey, points out, however, that amidst all the media-inspired dystopian doom and gloom, the reality 'is far more nuanced and positive than the headlines would suggest: advances in technology create new employment opportunities for people with the right skills and specialist knowledge. Last year, for instance, we looked across 140 years of history in the form of census and labour force data to demonstrate that technology creates more jobs than it destroys.[73] [74]Indeed, between 2001 and 2015, we estimated that even as technology had contributed to the loss of 800,000 jobs in the UK, it had helped to create 3.5 million more in the same period. Each new job pays,

on average, an additional £10,000 per annum, resulting in a boost of £140 billion to the UK's economy in new wages.

David Autor, Professor of Economics at MIT, suggests that "journalists and even expert commentators tend to overstate the extent of machine substitution for human labour and ignore the strong complementarities between automation and labour that increase productivity, raise earnings, and augment demand for labour."[75]

As Carl Benedikt Frey put it in his work on the Future of Employment with Michael Osborne: 'Technological progress has two competing effects on employment: first – as technology substitutes for labour, there is a destructive effect, requiring workers to relocate their labour supply … and second, there is the capitalisation effect, as more companies enter industries where productivity is relatively high, leading employment in those industries to expand.'[76]

We are brought back to Professor Hall and Mr Pesenti's argument about skills and AI, that 'the more people who have the right foundational STEM skills, the more can train in the higher skills, but also more will be able to work in adjacent roles: working in and around AI rather than developing it at the most complex levels. Accessible training that helps people with the right basis of knowledge to make this transition would help expand supply of AI professionals, and could help to develop understanding of how AI can deliver value among a much wider group.'[77]

The Royal Society's report After the Reboot, cited several times above for its analysis of the state of computing education in schools, makes a similar point about the potential of Robotics and Artificial Intelligence to create prosperity and employment if the workforce is sufficiently skilled to take advantage of the opportunities offered, saying that 'while artificial intelligence will almost certainly redefine work in many industries, it will also lead to net new industries, companies and jobs, many of which are difficult to even conceive at this early stage. In fact, study after study, from the most respected economic scholars and research organizations in the world, indicate that technological advances like AI lead to net job growth. Perhaps the Organisation for Economic Cooperation and Development (OECD) said it most unambiguously: "Historically, the income generating effects of new technologies have proved more powerful than the labor-displacing effects: technological progress has been accompanied not only by higher output and productivity, but also by higher overall employment."[78]

Or, in more journalistic terms, from the World Economic Forum: 'It is reasonable to infer, given this background, that large-scale human redundancies caused by transhuman AI are fanciful, at least in the near-term horizon, given the actual performance of automation and the gaps in the enterprise today. What is more likely is the proliferation of mid-tier AI systems transforming the capacity of mid-level skilled workers to better fill vacant jobs and to *participate* in human-critical automation of the enterprise, and in the search for novel business methods and models.'

'With superior virtual reality and machine-iteration systems, average food technologists can carry out a more varied range of biochemical explorations. Nurses can perform a wider range of imaging tests. Fashion design trainees can contribute more effectively to the fabric technology sourcing process. And so on and so forth. With improving personnel agility comes more nimble business models and an expansion of the job market.'

'Add these prospects to the potential productivity lift and the better synching of job openings and personnel availability and a whole new vision of what pro-human or cis-human AI might do for the job market emerges, one that is starkly different from the dystopian prophecies tethered to the rise of trans-human AI.'[79]

Collaborative Robotics

In his White Paper on manufacturing robotics, Dr James Law, Senior Experimental Officer and leader of the co-botics group at Sheffield Robotics, has a vision of the near future that 'soon the factory of the past, limited to producing only identical products, will be transformed. As researchers develop more intelligent and flexible robot capabilities, these technologies will help manufacturers lower the cost of reconfiguring their production processes for smaller batch sizes of a wider variety. In doing so, they will be able to tailor each product to their customers' needs and move up the value chain, whilst being less reliant on a low skilled workforce. Through these changes, the Factory of the Future will focus on high value, mass customisation.'[80]

So, robots will replace some labour, taking industrial jobs, but what they will replace are the more low-skilled, repetitive and dangerous jobs on the factory floor, while 'a new generation of "collaborative" robots will also enhance the impact of intelligent automation by maximising the abilities of both humans and machines. As robots become safer and allow close working with humans, the potential applications widen beyond the traditional industries of aerospace and automotive to food and drink, agriculture, biotechnology and the creative industries which are already adding robotic co-workers to their ranks. Based upon preliminary results from an EPSRC sponsored survey by University of Sheffield, University College London and University of Warwick on human and robot interaction, factories of the future will be developed to be adaptive and smart manufacturing systems. They will use intelligent robots and machines that cooperate both among themselves and workers in a safe, autonomous and reliable manner to support capabilities that otherwise would not be possible.'[81]

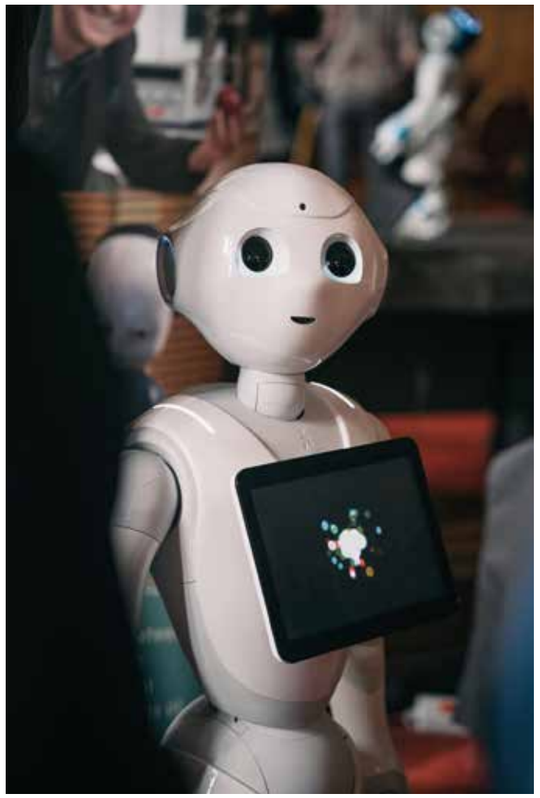
Dr Law uses the example of Tesla, for instance, to elucidate the potential of collaborative robotics to create rather than decimate industrial employment: 'The conventional thinking is that companies are buying robots to replace people. In contrast, many companies are using robots so they can expand and improve product quality and increase production. For example, in the case of Tesla Inc., investment in automation has led to the hiring of more skilled engineers and sales staff to support growth.'[82]

The authors of the Made Smarter Review offer more examples of companies whose use of collaborative robotics (or 'cobots') can augment employment as well as productivity: 'At BMW's US factory in Spartanburg, cobots help fit the company's car doors with sound and moisture insulation, a task that used to cause wrist strain for workers. Canadian electronics manufacturer Paradigm Electronics uses cobots to carry out delicate polishing and buffing tasks on loudspeakers, working with employees who handle the final finish and quality check. These robots have led to a 50 percent increase in productivity, but with no job losses – employees who previously carried out these tasks have been promoted from machine operators to robot programmers.'[83]

The Review sees in collaborative robotics 'an opportunity for the UK to differentiate itself in this digital industrial revolution. The relatively flexible and competitive UK labour market has allowed many companies to achieve world-class productivity at lower levels of automation. This will provide an even stronger competitive advantage with Industry 4.0 technologies like 'cobots', where humans work in harmony with advanced technologies to create highly agile businesses attuned to the changing needs of their customers.

But, other countries are stealing a march on the UK. There are coherent government strategies in place in most developed countries, for example in Germany (Industrie 4.0), China (Made in China 2025), and the USA (America Makes). So, the UK needs to act quickly if it is to harness the potential of this agenda.'[84]

If the UK is to indeed act quickly to take advantage of the opportunity to put itself at the forefront of Industry 4.0 by exploiting its potential strengths in collaborative robotics, as with AI, it will need to build 'a workforce that can best exploit such technological advancements' in Dr Law's words, and furthermore be mindful that 'without support for further training and education in RAS and related ICT technologies, UK firms will not have the skills to react to changes in the global market compared to other competing economies.'



Part_2_ OVERVIEW_OF_CURRENT_ SKILLS_INITIATIVES

With schools currently struggling to produce the requisite skilled future workforce, and the funding crisis in further education colleges rendering them unable to provide an adequate level of adult skills training, what seems to be required is the kind of 'multi-stakeholder collaboration' in skills provision that WEFO's White Paper[85] encouraged. Central to such multi-party collaboration are Britain's universities.

The Made Smarter Review; the Department of BEIS' Green and White Papers on industrial strategy and the DCMS' Growing the AI Industry in the UK review all agree that universities should play a major role in helping to address the skills deficit in light of Industry 4.0. From the credit-bearing MOOCs and online STEM CPD courses recommended by the AI review to the potential HEIFF-backed skills partnership initiatives, Innovation Clusters and Local Industrial Strategies proffered by the BEIS Industrial Strategy White Paper, as well as the proposed Made Smarter Skills Strategy and Implementation Group, universities are expected to work alongside the wider public and private sectors to 'improve skills, increase innovation and enhance business growth'.[86]

This section will examine some skills initiatives at Sheffield University, the city and beyond and explore what key stakeholders at the university see as their role in upskilling the British workforce in readiness of Industry 4.0.

Collaborative_Robotics_and_ Skills_at_Sheffield_Universitx

An_interview_with_Dr_Iveta_Eimontaite,_ Research_Associate_Department_of_Automatic_ Control_and_Systems_Engineering.

Dr Eimontaite discussed with us her work alongside Dr James Law on collaborative robotics and methods to manage negative attitudes towards robots and robot anxiety in human-robot co-working. She sees one of the central problems of British industrial workers adopting the latest technology and learning the requisite skills to work alongside robots to be that of acceptance, in short that workers don't trust robotics and fear that robots will take their jobs. Dr Eimontaite feels that workers' anxiety about robotics and the future of human-robot collaboration largely stems from a lack of accurate information and that general public perception of robotics is largely derived from the media – film and science fiction – in which robots are more advanced than they are in reality. The robots depicted in films are generally 'really scary; and the prospect of the future is scary'.

Over the course of the research project at Sheffield Robotics[87], in which workers were invited in to engage with robots and discuss robotics with staff members, who attempted to answer questions put to them about robotics and how they see the future of human-robot collaboration – many of the workers' anxieties were resolved.

Initially, two groups of ten industrial employees from a factory in which robots were just about to be installed were invited to the lab at Sheffield Robotics to discuss their anxieties and engage with robots in the laboratory. The workers were first asked about their attitudes to robotics and how they see the future of human-robot collaboration and of the future of manufacturing in general and what role they saw robots playing in it. They were then given a guided tour and could meet, touch and otherwise engage with the robots and ask the attendant academics any questions. Dr Eimontaite reports that safety was the primary issue that the industrial employees were interested in discussing; most were working with welding equipment and were keen to discuss ways in which working with robots could improve their safety. With a robot between them and the welding equipment, they saw how collaborative robotics would make their jobs safer; there would be fewer accidents and in the end 'they were more eager to interact with robots than with the welding machines.' By the end of the workshop, there was a 40% drop in the workers' fear of robotics and anxiety about working alongside robots. Good directions – in terms of signage and information provided by the academics at Sheffield Robotics – were also shown to be significantly important in easing the anxieties of the co-workers and increasing their productivity working with the collaborative robots.[88]

Dr Eimontaite concluded that effective public engagement is vital to aid acceptance of robotics and encourage workers to upskill themselves to work alongside robots. 'We all know that changes are going to happen' she says, 'the important thing is to involve people in those changes, so that they happen with people, not to people.' When the factory workers had actually interacted with robots, seen what they can and can't do, and discussed what aspects of their jobs they would like robots to do for them, they were far more open to robotics and to working collaboratively with them. Dr Eimontaite went on to discuss how engagement is important for people of all ages; a public engagement exercise that she carried out with 3-5 year-old children at the laboratory was also highly successful in her view. She found that the children were far more accepting of robotics, excited to be in the presence of actual robots and curious about what they could do, so that in the end, the children 'wanted to do more things and weren't afraid of technology but encouraged to work with it.'

Dr Eimontaite felt very strongly that there needs to be more collaboration between academia and industry to help the British workforce embrace new technologies and seek to acquire the skills they need to work effectively alongside it. The research she has carried out at Sheffield Robotics with Dr Law demonstrates that if people are engaged with new technologies, by getting the opportunity to interact with it, they feel far more empowered to actively participate in technological change. 'We must get the expertise and technology out of the university and into the field' she told us, 'without industry and universities working together; without engaging the public, and children, sufficient progress won't happen.'

Just as important as public engagement is the research to follow it up, says Dr Eimontaite. She calls for more time to study the data generated by public engagement and to conduct more experiments in engagement so that the engagement itself can be continually developed and improved.

Interview with Dr Gwendolen Reilly, Senior Lecturer in Bioengineering at Sheffield University and Faculty Director of Women in Engineering.

Dr Reilly started by discussing public engagement events that she has recently been involved in – such as the International Women in Engineering Day event held every June at the Winter Gardens in Sheffield and the annual Sheffield Festival of Science and Engineering. Dr Reilly prizes public engagement highly, finding it an important way to attract people to a career in STEM and science. Events such as those above are good for showing people the latest technologies and letting them interact with them. Especially in the case of engineering, Dr Reilly commented that people often don't understand what engineering actually is, that it's not just a case of fixing people's broken washing machines or working with cars in garages but can be an opportunity to work with the very latest technologies, that people at the events can see there before them, in a host of different roles. The key thing, she related, was not trying to force young people into any particular field, but to inspire them to get interested in engineering as a broad field with lots of exciting and engaging technologies.

Public engagement can be a vital way to attract girls and women into engineering, she thought. As Faculty Director of Women in Engineering, Dr Reilly expressed her pride that her department has managed to push the ratio of women studying mechanical engineering up to 20%, and the faculty as a whole up to 22%, but these figures are obviously still very low. 'You're not going to get more female post grads if you haven't got the undergrads and you're not going to get the undergrads if girls aren't doing the right A Levels, and so on.' What with general social stereotyping, a lack of female role models in science and the gender issues in STEM teaching at schools discussed in section 1 of this report, Dr Reilly believes that children are already effectively stereotyped by the time that they are seven years old and hence that it is vitally important to engage with younger children before the social conditioning has taken hold.

As Dr Reilly said, though, 'how many age groups can we target? We're universities and we have to think primarily of the people who are ready to come to university. Our main problem is that there aren't enough girls doing physics A level. How we're trying to deal with that is doing extra physics training in the summer and other activities like that. It's a bit ridiculous that that's what we have to do but it's the only way to address the balance because there's such a small pool of people to draw from if it's only girls who have physics A level.' Dr Reilly went on to explain that 'We know that in the long run, the only way to get more female undergraduates is with long-term cultural change that makes engineering more accessible to female students and that the way to do that is with public engagement and getting the message out there.' The problem, though, is that for academics such as Dr Reilly, the immediate priority has to be to 'getting bums on seats in the university in the short term; recruiting undergraduates.'

Dr Reilly sees great value in wider public engagement, however. In terms of adult education, she feels that introducing the older generation to robotics through public engagement initiatives is key to reskilling the workforce, just as it was 'when computers came in' and the older generation then had no experience of digital technology. If people who had had no previous experience of robots and AI could meaningfully engage with them, they would lose their fear of the future and new technologies. She sees a strong parallel between current attitudes to R&AI and public attitudes to bio-engineering ten years ago when scare stories in the media about genetic engineering in crops and human gene manipulation dominated the agenda and fuelled a public backlash against GM. What Dr Reilly thinks turned public perception around then was a general public engagement campaign by bioengineers – getting out there into the media and public sphere with more positive stories and better information and explications of the issues at hand. She cited the public engagement work of her Insigneo colleague Professor Marco Viceconti and the Insigneo Showcase to demonstrate the potential benefits of in silico medicine and allay the public misconception 'that we are all going to be replaced by computer versions of ourselves.'

Like Dr Eimontaite, Dr Reilly stresses the need to combine more public engagement with research so that we can develop the most productive engagement methodologies and follow the long-term consequences leading from the initial inspiring contact with new technology. As she says of the annual Women in Engineering Days that she helps run at the Winter Gardens in Sheffield – 'they're always full and you certainly get a very positive response. All we know is that there has been a slight increase in engineering applications from women, but it's very hard to measure effects in the short term'. Ideally Dr Reilly would like to track the children who through the Winter Gardens events to see how many did engineering in 15 years' time, but at least she would like the opportunity to study robust data generated by public engagement events such as the Women in Engineering Days.

Interview with Professor Jackie Marsh, Professor of Education, Sheffield University.

Professor Marsh specialises in young children's digital literacy and started by saying that the STEM skills deficit in the UK is an issue that starts early in children's lives. She advocates the use of play and art in teaching STEM to young children and bemoans the fact that coding and computing are currently taught in an isolated, itemistic manner as a separate skill rather than as an integral part of a wider education including the arts and humanities. Robotics, she feels, also has an important part to play in engaging young children in programming and that a wider STEAM approach really is attracting young children and especially girls to computing. It is important, she says, to get enthusiasm going right from the early years to inspire children and fully engage them in technology. STEAM – the approach to teaching STEM using the arts first coined at the Rhode Island School of Design – is a highly effective method for teaching children at a very young age, Professor Marsh believes, relating that 'we had 3 and 4 year-olds learning coding'.

The key to Professor Marsh's success was making coding enjoyable for young children, learning how to make simple circuits 'in a way that was fun for them'. Similarly, Professor Marsh found it important to combine formal and informal educational settings, using libraries and museums as well as schools; places where more project-based activities can be enjoyed and revisited, so they can code and hack without necessarily having an end product, encouraging risk-taking and problem-solving, engaging them in coding by allowing them to enjoy it as play. Such open-ended,

non-formal education, of creative 'Making' is the best way, in Professor Marsh's opinion, of engaging young children and inspiring them to potentially follow a career in STEM and science. She looks forward to publishing the findings of her research project Makerspaces in Early Childhood: Enhancing Play and Creativity (MakEY) 2015 – 2019 at the beginning of next year since there is currently very little data available as to the effectiveness of making as a pedagogical approach for young children.

Making, as a way to bring more people into STEM, to inspire and engage disadvantaged communities and to foster a culture of reskilling and upskilling in new technologies, also has a much wider role to play. Professor Marsh sees Making as a way for universities to make an impact in reducing the STEM skills deficit in the UK by setting up afterschool clubs, weekend hackathons and adult and family activities in the surrounding communities. An outreach program from Sheffield University, for example, provides Makerspaces for 6-10 year-old children in a local Somali community, with university students volunteering to share their expertise. 'If you can inspire the children' Professor Marsh says 'they might share that with their teachers and inspire them'. She sees this kind of 'pincer movement' of formal STEM education in schools alongside a robust informal system of afterschool clubs, community groups and hackathons as the best way as it stands to bring people to STEM.

Maker clubs could also offer teachers an opportunity for professional development, to improve their coding skills along with the children and other members of the community in the clubs, and partake in a more experiential, playful and open-ended way of learning. It's also very important to involve families. If you can inspire a 5 year-old, Professor Marsh thinks, you might pull in their 15 year-old sister, or even their parents. 'Young children are often the best way into families'.

Although urban areas such as the Sheffield City region, Barnsley and Doncaster do now have a fairly robust network of Making clubs, there is a dearth of them in more rural areas, a lack that Professor Marsh feels the university could do more to resolve. One idea that Professor Marsh is very keen to actualise is to start a Maker bus service to more rural areas around Sheffield. The bus would be peopled by volunteer students and kitted out with Making equipment by the university. Primarily, it would travel to rural libraries to set up shop and invite local families in to experience Making first hand. Having some female student volunteers on the bus would also help to provide strong STEM female role models. 'The libraries are very keen on this' Professor Marsh relates 'we ran Makerspaces in Sheffield libraries last autumn and they had new people coming in and joining the libraries with their children. They're very keen to host these.' Sheffield Council is apparently also keen to get on board. Perhaps a Maker Bus project, initiated and trialled around Sheffield could be a good model for a UK-wide network of Maker Buses servicing the rural areas around universities and STEM education

centres. There is also plenty of potential for the project to work with robotics, using simple technology to build and program elementary robots, both to offer interesting coding outcomes in the Maker space and to more generally engage people with robotics.

Professor Marsh doesn't know of any similar projects in the UK at the moment but has visited the Fab Lab in Berlin that runs a highly successful Maker engagement project in Berlin and uses a caravan to reach more rural areas around the city[89]. Such 'bottom-up' activities are more likely to imbue people with the more 'integrated knowledge' and transferable skills such as team-work, communication, creativity and problem-solving that will be required in future industry. Equally important is to be more open-minded in working with more technologically disadvantaged communities, 'asking them what they need' and adapting our work accordingly when researching such public engagement initiatives.

As well using undergraduate and graduate volunteers on the buses, or in Makerspaces generally, Professor Marsh is keen 'to bring in the Makers' to enthuse and inspire people into STEM. 'These are people who have been working for years, often with open-software tools, in their own communities. They're very skilled and knowledgeable people; it's about drawing their skills and knowledge in.' Professor Marsh relates that she has been working with James Wallbank, for example, who runs the Access Space Network charity[90] and a Makers shop in Sheffield, on projects working with 3-4 year-old children to enthuse and inspire them into a life of Making and STEM.

Makers such as James Wallbank and potential initiatives such as Maker buses could also be highly effective in reaching adults in more technologically disadvantaged communities. Again, Professor Marsh feels that it is important to consult and collaborate with such communities as to their needs and design projects accordingly, using Maker technology to solve real-world problems in community settings so that communities themselves can invent and create the tools they need to address problems they face. 'You can have multiple projects and multiple age groups' Professor Marsh says 'it's not too late to enthuse someone around STEM - there's an urgent need I think for early and mid-teens, to orientate them towards these areas'. Female role models are vital in such work if more women are to be encouraged to pursue STEM careers and adopt more STEM skills. 'That is how MakEY[91] started' Professor Marsh relates 'I went to the Fab Lab in Berlin and they were all male. I thought to myself: this can't be right, we've got to get girls interested.'

Some skills initiatives outwith TUOS

Interview with Catherine Elliott, eLearning consultant, Sheffield City Council.

Catherine Elliott started the interview with us by discussing her successful Nesta-funded Make:Learn:Share project, a citywide 'Made in Sheffield' Young Ambassadors programme, looking to train 135 year 8 & 9 schoolchildren in digital making for them to then deliver technology workshops to younger children in local primary schools.

'We've done really well at recruiting girls' she told us. 'We've had good gender splits and a couple of all female groups.' Catherine remembers that their initial aim was to get a 50/50 gender split in the young ambassadors' groups, or at least good female representation, 'but a lot of the teachers in Key Stage 3 decided the program would be a good way of trying to get year 8 and 9 girls enthused in computing before taking their options, so some made a decision that they were going to actually target the girls.' She considers that the fact that she and fellow project leader Sue Finnigan are women helped in attracting so many girls to the programme, being good role models for them, but says that it also grew out of how they set up the coding project, 'by including design, social aspects, ethics and making it a more rounded experience to attract a wider range of young people.'[92] Mrs Elliott reckons that overall 'We've trained approximately 150 students from year 6 to year 10, and probably just over 50% of these were girls. One school brought 100% girls to the training session.

'Real-world' activities are also seen by Catherine as being a good way to bring girls and young children generally to STEM. Whereas schools don't have sufficient space in the curriculum and school day for children to enjoy many extra-curricular activities, the Make:Learn:Share making sessions offer children the opportunity to experiment more in open-ended activities and to talk around computing. 'Students are very interested in the ethics of robotics and data' for example 'I've seen how motivated these kids are by having lots of different ways into technology.' The idea of being an ambassador and teaching coding to other younger children, instead of just learning it, has also worked in engaging girls.

Mrs Elliott highlighted recent work by The Salters' Institute and Salters Horners in attracting more girls to science by developing real-life, practical physics and chemistry projects to engage children and get them more interested and active in non-formal educational settings such as the Salters' festivals and summer camps.

The Salters' Institute serves as a useful model to follow to improve the teaching and general acceptance of particular subject areas and disciplines. As we may look to do with Robotics and AI, the Salters' Institute has worked, for a hundred years this summer, to open chemistry, and recently other mainstream sciences, more to the public, to make it more accessible and attract a more diverse group of people with informal, hands-on learning and widespread public engagement. The Salters' Chemistry Festivals, for 11-14 year-old children, have now been running for over 25 years. About 800 schools now participate in 50 festivals held annually throughout the UK. Although the university-based Salters' Chemistry camps have now stopped running, the Institute estimates that they attracted nearly 10,000 students and are now the basis of the "Inspirational Chemistry Programme' run by Salters and the RSC in India. The Institute's work in curriculum development - developing new GCSE and A level courses and practical initiatives - has been so influential that it has become known as the 'Salters' Approach'.

With a dearth of female role models in STEM being repeatedly highlighted as a major reason for the disconnection of girls and women from STEM and STEM careers, Mrs Elliott would also like to develop an engagement project using 'talking head' short films of women in industry speaking directly to the camera about their experiences. Such talking head films could also work to show children that there is a whole range of computing and STEM jobs that aren't just coding and pure science, but that STEM can lead to jobs in the creative industries as well. 'The films could feature young people in the creative industries around Sheffield – web developers and music technologists for example – who could describe what they do and the skills that they needed to get there.'

Mrs Elliott was also very interested by the idea of a Maker bus as an engagement tool. 'It would work' she said. 'The problem in schools is that there is no time or money; schools can often only dedicate an hour every fortnight to teach computer science, so they need the help of universities and businesses to provide real-world experiences around computing. Something mobile like a bus that can get to people who aren't currently engaged and who need the skills would be really interesting. We could use the young ambassadors to help. There's a huge desire in schools to address the gender imbalance in STEM and if we went to them saying that we could do a roadshow to address the imbalance, the schools would be really keen to help'

Providing multiple routes into technology has proved highly successful in attracting children and girls to the Make:Learn:Share project but Mrs Elliott also believes that such an approach serves them well in giving them the skills base that they will need later in their lives. 'Look into the future and it won't be all about how to program but that everyone will have to be aware of how technology impacts their jobs.'

Interview with Howard Baker, creator of the Micro:bit and consultant on education and technology.

Howard Baker, creator of the Micro:bit, told us that although schools remain the easiest and most efficient way to reach large numbers of children, training the teachers themselves is vital if the children's computing and STEM skills are to genuinely improved. As reviews such as the Royal Society report on Computing in Schools and the DCMS' report on growing AI in the UK attest, many computer science teachers did not originally study computing at degree level but instead have backgrounds in ICT or DT and lack the requisite skills to teach the pure computing segments of the GCSE. As Mr Baker says – 'it was just about working with Excel or Word and treating the computer as a black box, teachers didn't really need to know how the computer was actually working'.

With the support of Microsoft, the Micro:bit Foundation found that the open-ended, hands-on pedagogical approach of teaching teachers about computing using Micro:bits was highly effective, largely because it enabled teachers to gain confidence in their understanding of computers and ability to teach children. After preliminary CPD sessions using Micro:bits, 'the percentages in perceived confidence were very high, approximately 80%, and we've seen that repeated using Micro:bits in teacher training in other countries as well'. Rather than being anxious about their ability to understand and then teach coding, teachers found that simple 'drag and drop' technology of the Micro:bit relatively easy to comprehend rather than more complicated technologies such as the Raspberry Pi or Lego Mindstorm. 'Teachers must feel confident and it must be very simple. They need to be able to take something out of a box, the kids can do what they need to do, and the kit goes back in the box again.'

'It's a step by step process', he says. 'if you're a novice at computing and coding, learning elementary programming with the basic Micro:bit can be made easy with the right support; we tried to make it as easy as it could possibly be. It's only once they have the initial experience, once they have grasped it and seen how easy it actually is and seen the children using it, that they consider moving on to the next stage of Making, attaching wires or speakers or joining creative networks. Then teachers start to think I could possibly build a robot and I could join or support a Making club or coding club. The main thing with the Micro:bit is that you can take it out of the box and have it doing something in five minutes, sending text messages or animation smiling, after just two or three instructions. It makes everyone pleased with what they've managed to achieve. It gives them confidence. We see it very much as a skills-based tool. It's very much about creativity and about thinking skills and computational skills and computational thinking.'

These are the skills, Mr Baker thinks, that we will need in the future – problem-solving skills using technology, overall STEM skills. Although the individual scientific subjects should still be taught separately, children should also experience STEM as a whole. 'Some schools are able to run STEM projects in the background, like the Micro:bit Race for the Line rocket car competition,[93] where kids design rocket cars. They use maths, science, physics, chemistry and engineering all together; or the American Lighter than Air project, where they get to design and build unmanned aerial vehicles - projects like this create an umbrella around STEM. We need more projects like this, a nationwide robot project would be perfect. Teachers don't want to create them themselves, but they would join in if a good project came their way and it had good publicity. There is the feeling that project-based learning can lead to good exam results in the separate STEM subjects.' What the BBC tried to create was a 'real-life problem-solver not just a coding tool.' 'Informal learning is extremely important' Mr Baker continues, 'we should be doing the utmost to facilitate, enhance and create access to informal learning. It builds confidence and awareness', we should do everything we can 'to give kids meaningful contact with technology.'

The gender split in STEM is also an important issue to Mr Baker. As referenced in Section 1 of this report, he feels strongly that we must try to provide female role models and access to STEM for girls; STEM must be made more socially acceptable as a career route for women. 'We tried to make the Micro:bit as gender neutral as possible' he says, 'the design, the access to it and most importantly the awareness of what can I use it for?' Mr Baker does feel that more girls are getting engaged in STEM at a young age; and that more Micro:bit projects coming through are involving girls. One reason, he thinks, is awareness – that more girls are aware of STEM challenges and competitions and that more girls' schools are taking part. Crucially, girls are starting to win the challenges. 'Once girls win more and more competitions, they can act as role models, making it more socially acceptable for girls to get involved.'

'Gender and the older generation are the two big audiences that we have to look at in terms of skills' Mr Baker continues. He says that he is keeping a close eye, for example, on an engagement project in a housing estate in Lewisham, in a deprived area of London. The engagement project is seeking to give six thousand householders access to new technology, Making and building. Without such opportunities to engage with technology, 'we'd be looking at a dying community', Mr Baker feels. He cites another project, at the Knowle West Media Centre[94] in Bristol, whose aim is 'to help individuals and communities get the most out of digital technologies and the arts'. Twenty years ago, when the project was first launched, the core technology was media but is now Making and producing, also providing 3D printing facilities and the use of a pop-up furniture factory. The project is now also looking to set up a Bristol Maker Lab. Mr Baker sees such initiatives as vital ways to help disadvantaged communities get access to technology; he also cites the Digital Garages community project in Singapore[95], which uses Micro:bit computers to introduce the community to Digital Making.

As well as bringing Making to communities as a way to engage them with technology, through its simplicity and 'real-life' problem-solving potential, Mr Baker believes that intergenerational learning can also be highly effective. He uses as an example the 12 year old Maker and young coding ambassador Femi, also known as Hackefemo[96], who runs technology workshops and courses and advises businesses, including running a Micro:bit robot workshop for the cyber security division at PWC, as well as his work in community coding and Making events. 'Use kids as ambassadors' Mr Baker says, 'Femi is a very good example. He does amazing work.'

Interview with Seb Rose - Software Developer, author and analyst.

Seb Rose agrees with many of the interviewees above that it is not coding per se that we need to be teaching young people for them to thrive in Industry 4.0 but giving them a good grounding in STEM. As well as his professional experience as a software developer and analyst, Seb has experience in teaching and engaging children in a First Lego League Club[97] and in coding clubs in Scotland.

He finds that the 'fixation with programming is misplaced' and that the huge worldwide success of the First Lego League is that 'it gets children into STEM, it shows them that it isn't hard or unachievable or only done by rocket scientists' but is a skill, like computer design, that is easily learnable and gives the children confidence that they can succeed in science. The First Lego League is similar to the STEAM approach to engaging people in science, Mr Rose believes, in that players 'might use drama or poetry to deliver the findings of their research; they're encouraged to be as creative as they like.' Prior to that, they have had to use key STEM skills in identifying a problem, such as how you can clean water, or transfer water, then talking to experts about the problem, thinking of an innovative solution to the chosen problem and then presenting it back to the professionals for their feedback.

Seb's experience running coding clubs has shown him that what is important is to show children that coding itself isn't necessarily difficult. 'Drag and drop interfaces help novice coders think about fundamental coding constructs such as looping and conditionals and realise that coding isn't that complex; like computers themselves, it's made up of lots of very simple things. Once you've understood what the simple steps are it's just how you express it. Programming languages change, fashions in programming change, so

whether it's python or javascript, it doesn't really matter. The important thing is that they see that it is just made up of lots of simple steps that they can do.'

Thinking about the skills that the next generation will need to thrive alongside the new technologies, Mr Rose surmises that 'there'll be fewer and fewer coders. The problem is never finding enough coders, what we'll need is communication skills, domain expertise and understanding some of the constraints and limitations of the platforms. Whether you're a coder, an engineer or a scientist, what everyone needs is a general understanding of what's going on.'

'Coding clubs, Lego League clubs, engineering clubs – all these clubs are good – just for getting young people engaged early and showing them that they don't have to be a top student in anything to do it; we specialise too early as it is. The main thing is to demystify science and computing. Computers aren't off limits and impossibly complicated. Everyone can do it.'

'Seb feels that we should 'give kids a broad understanding of what's going on.' What employers want is 'people that can adapt, someone who can work in a team and has broad knowledge – your classic T-shaped person – broad knowledge in a domain and deep knowledge somewhere. Put them in a team and as long as they have good communication skills, they'll be fine.'

Interview with Dave Gibbs, Computing and Technology Specialist for STEM Learning.

As well as his analysis of the STEM skills deficit in the UK and of the teaching of computer science in secondary schools covered earlier in this report, Mr Gibbs also spoke with us about some initiatives that he has been involved in to address the gender imbalance and improve STEM skills generally.

As part of STEM Learning's remit to broaden the audience for computing and STEM, Mr Gibbs has been involved with the highly successful STEM Ambassador network, in which volunteers from industry and other STEM-related occupations go into schools and STEM clubs to talk with children about their work and the attractions of a career in STEM, as well as offering mentoring and practical workshops. 30,000 STEM Ambassadors from more than 2,500 different employers have so far taken part in the scheme, helping to build an ambassador network based around 19 hubs throughout the UK. Mr Gibbs described how the main thrust of the clubs and ambassador network is to engage people with STEM and get them interested in a future STEM career. Good role models, he feels, can make a big difference to how children perceive STEM as a whole, and the ambassadors, by being real-world people that the children can relate to directly in the classroom or club, can have a big impact. It is very important to have female ambassadors going into the schools and clubs, since there is currently such a dearth of good female role models in STEM and many girls feel excluded from a potential STEM career.

In STEM Learning's new Little Big Futures Projects[98], in which kids are encouraged to engage in STEM by being given real-world problems to solve through coding and technology, Mr Gibbs has found that it can work to separate boys and girls to prevent louder boys dominating the sessions 'with their little bit of extra knowledge'. Since boys sometimes have a head start, gaining their 'little bit of extra knowledge' practicing coding at home, it can be useful for the girls to be in single gender groups for the early classes, or at least be given separate spaces while they learn the fundamentals in the first few sessions.

Mr Gibbs also highlighted the Raspberry Jams, originated by STEM Learning, which have grown into an international network of community events based around Raspberry Pis. The events are day-long Maker sessions with lots of workshops and opportunities for children to share Raspberry Pi projects that they have done. 'Making is a great way to get kids really engaged with technology' Mr Gibbs thinks. He also cites the work that the Micro:bit Foundation has done; leading the way in making engagement and establishing young Maker communities, first in Britain and now worldwide. 'It's all about lowering the barrier to technology and STEM' he feels, also highlighting the importance of getting children's initial contact and engagement with STEM right. 'Before Micro:bit, there wasn't anything good at the initial engagement level', Mr Gibbs feels. 'But the interesting thing now is how we take it on from there'.

Mr Gibbs largely agrees with Mr Rose's thoughts above about computational thinking rather than coding per se being the skillset that employers now and in the future will require as Industry 4.0 gathers pace. 'Computational thinking can be a confusing term, but it basically means enabling people to think about solving problems with technology. AI on its own and people on their own are not as strong as both together.' What we're encouraging people to think about is 'how can I solve problems using machines to work with me? What we need is a fundamental literacy of understanding what machines do, how you define problems and what the limitations of machines are. How we get people working with machines: that's the future skill.'

The key, Mr Gibbs feels, is to 'give people exposure to new technologies and highlight the skills that they keep re-applying in solving problems with it'. Mr Gibbs relates how there's currently some good work being done in primary schools with explicit goal labelling – helping children decompose problems and understand that they are using the same adaptable STEM skills every time. With such an adaptable core set off skills, the future workers of the fourth industrial revolution would have the tool kit they need to work

alongside machines and solve whatever problems industry throws at them.

Imbuing people with a core set of STEM skills is the best strategy we can employ. It's difficult in secondary schools, however, where the individual subjects are siloed because exams have to be passed and targets met. 'Extra-curricular groups and initiatives are probably the only way to implement it now.'

Part_3_ CONCLUSIONS_AND_ RECOMMENDATIONS

CONCLUSION

If we are indeed to 'reap the greatest rewards' from the opportunities presented to us by Industry 4.0, as the Business Secretary wrote, we 'need to prepare to seize them'[99]. Instead of fearing robotics and AI, two of the main drivers 'turbo-charging' the fourth industrial revolution, and lamenting the economic and social disruptions that they might bring, we should embrace the opportunities that they provide and trust that now as previously the 'income generating effects of new technologies have proved more powerful than the labour-displacing effect'[100], leading to higher not lower overall employment and prosperity.

Following Goldin and Kastz's well known maxim that industrial revolutions represent a race between technology and education[101], the key to the UK fully embracing the opportunities offered by Industry 4.0 is skills and education. 'Investing in all our skills is at the heart of building an economy that is fit for the future' as CBI director-general Carolyn Fairbairn put it so succinctly. 'Skills are vital to competing globally – and seizing the opportunities of the fourth Industrial Revolution'[102]. As we have seen from the many responses to BEIS' Green Paper Building Our Industrial Strategy[103] and from the several other sources quoted in this report, it is vital that we acknowledge and confront the current skills deficit in the UK by meeting the inherent weaknesses in our skills base head on.

As well as the skills in robotics and related ICT technologies that Dr Law tells us we will have to put in place if we want to compete with other major economies in the global market[104], it is also the more basic STEM skills of the population, developed through primary and secondary education and on into adult life, that the UK will have to improve if it is to climb up the skills tables and truly 'prepare to seize' the opportunities offered by Industry 4.0. As Professor Hall and Mr Pesenti put it in the context of the more adaptive skills that we will need to put ourselves at the forefront of the AI industry: 'the more people who have the right foundational STEM skills, the more can train in the higher skills, but also more will be able to work in adjacent roles: working in and around AI rather than developing it at the most complex levels.'[105]

A host of reports such as the highly influential review of computing education in schools published by the Royal Society last year highlight the current failure of the education system to produce enough 'people who have the right foundational STEM skills' or key digital skills, leading to the alarming figures cited in the Made Smarter Review that 'over 12 million people and a million small businesses do not have the skills to prosper in the digital era'.[106] In terms of computer science education, crucial to the UK attaining adequate foundation skill levels, '44% of secondary school teachers only felt confident teaching the earlier stages of the curriculum where there is less of a computer science focus'[107], while about a quarter of the secondary school teachers surveyed by the Royal Society reported that they hadn't undertaken any computing-related CPD in the last year to help them gain the requisite understanding of computing to teach others.[108]

Many commentators quoted in the report above point out that a major factor explaining our low relative international position in digital and STEM skill levels is our gender balance in STEM and digital education and employment. The figures speak for themselves. At GCSE, there is only a 20% take-up of girls studying computing, which falls to 9% at A level. Only 21% of the STEM workforce and 15% of the ICT workforce are female; women make up only 25% of those graduating from degrees in STEM subjects. The proportion in engineering is still lower at only 8%, with the unenviable consequence that the UK has the lowest percentage of female engineering professionals in Europe.

As well as the several published sources quoted above, our interviewees have also provided ample evidence that the current concentration on teaching coding per se as a means of attaining the requisite higher skill levels for the UK to prosper in the fourth industrial revolution may be insufficient. As Dave Gibbs, Seb Rose, Professor Marsh, Catherine Elliott and Howard Baker told us, Industry 4.0 will require a wider, adaptive skill set, centred more on creative problem solving and computational thinking rather than straight coding skill. As Dave Gibbs put it: 'What we're encouraging people to think about is 'how can I solve problems using machines to work with me. What we need is a fundamental literacy of understanding what machines do, how you define problems and what the limitations of machines are. How we get people working with machines: that's the future skill.' Many of the academics and experts interviewed above also see this more adaptive, agile, hands-on and informal set of skills and learning outcomes to be a more effective way of encouraging girls and women into STEM, especially technology and engineering. Crucially, it must be also made more socially acceptable for women and girls to engage in STEM.

As Howard Baker observed, the more informal approach to learning and engagement in technology that Making offers has in his experience helped attract girls to STEM and that by winning an ever growing number of Maker challenges, it will become increasingly acceptable for girls to pursue technological interests and careers. Making was cited by Professor Marsh as a key resource available to educators, Makers themselves being hugely knowledgeable and skilled in using technology to solve real-world problems. So effective is making, in eLearning consultant Catherine Elliott's experience, that her Make:Learn:Share project for Sheffield City Council has an approximate 50:50 gender split amongst its young ambassadors.

Several of our interviewees saw Making as an engaging way to introduce robotics to children, whether as a way of making coding more enjoyable and outcome-oriented or by building elementary robots to solve the kind of real-world problems that Mr Rose discussed from his time as a community educator in the First Lego League. Getting people making elementary robots, whether with Micro:bits or Lego Mindstorm, is widely seen as a highly effective method to encourage people of all ages into STEM and a way to lend real confidence to those who otherwise feel that coding and computing is beyond them. Both Howard Baker and Dave Gibbs saw robot Making as an ideal way to develop teachers' knowledge and confidence in computer science. Along with Catherine Elliott, Mr Baker also saw a highly effective and synergistic relationship between robot Making and intergenerational learning as a way to bring older people into STEM , engage them with technology and lead them to reskill. Professor Marsh particularly cites the Fab Lab in Berlin – with its Makerspace and mobile Fab unit – as a useful model to follow.

With schools currently struggling to produce enough 'people who have the right foundational STEM skills' and sufficient female representation working in STEM and digital careers, the spotlight falls on further and higher educational institutions to ensure that the gender split and base skill levels meet industry's requirements. As we have seen, however, in the words of David Hughes, Chief Executive of the Association of Colleges: "Further education has been starved of the investment needed to support young people and adults gain the skills they need for successful careers', let alone meet the Made Smarter Review's stipulation that 'two million people will potentially need to be upskilled or reskilled in the workplace.'[109] For the British economy and society to thrive in Industry 4.0, it is important that we establish a culture and system of continuous learning – upskilling and retraining – to optimize the availability and competence of the workforce. Effective adult skills training becomes ever more vital with our ageing society; increased awareness and acceptance of technology can give older people not just a more economically productive but also a more connected and fulfilling life in their older years.

With much of the issue being a structural one – that children are not leaving school with sufficient skill levels and that much of the current workforce lacks the skill levels that will be required by Industry 4.0, it is also too much of a job for universities alone to take on board. As Dr Reilly commented in terms of addressing the chronic gender imbalance in STEM 'how many age groups can we target? We're universities and we have to think primarily of the people who are ready to come to university'. 'The immediate priority has to be … recruiting undergraduates.'

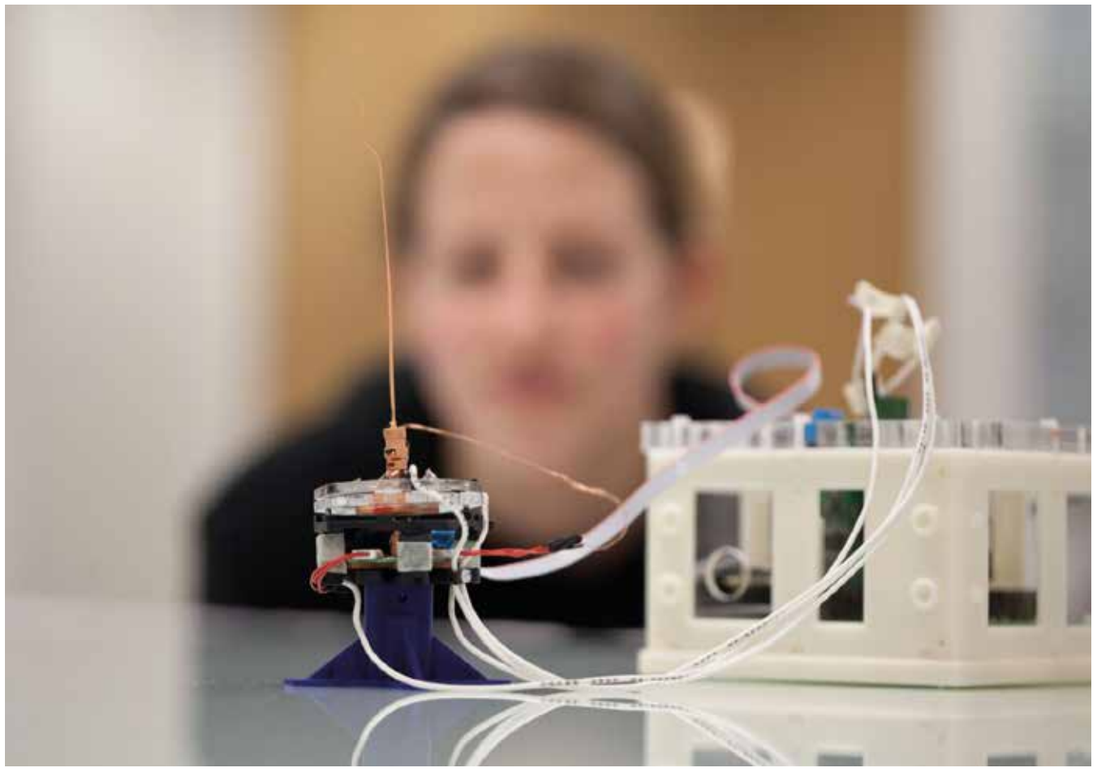
Along with basic skills, another major issue with the potential to prevent the UK maximizing the opportunities of Industry 4.0 and not pay heed to Professor Maier's observation that 'we haven't reached our full potential and have left too many of the opportunities arising from the Third Industrial Revolution to other nations'[110], is the public perception of robotics and AI largely fuelled by a dystopic vision of the future beloved of movies and the mass media that they will take human jobs and ultimately kill us all. As we have seen, however, the reality is far more nuanced in the words of the Deloitte Report written with Carl Benedikt Frey – and that 'advances in technology create new employment opportunities for people with the right skills and specialist knowledge.'[111] Collaborative robotics, particularly, offers an alternative vision of the future in which Britain especially can thrive.

Although universities alone are unable to confront and resolve the UK skills deficit in the light of Industry 4.0, there is a major role that they can play in partnering with private companies and training organisations in the kind of 'multi-stakeholder collaboration' in skills provision that WEFO's White Paper[112] on reskilling encouraged. With universities' backing, such collaborative bodies can research and implement the requisite methods to train the 'two million people [who] will potentially need to be upskilled or reskilled in the workplace'[113]. Such a body may also look at the work of partnering organizations such as the Salters' Institute, who confronted the skills deficit in chemistry with public engagement and outreach programs as well as curriculum development at GCSE and A level, working alongside the University of York. Led by the University of Bath, twenty five universities, including Sheffield, a founding member, are similarly linked to the *Institute of Coding*, which helps address the digital skills and computer programming deficit in the UK.

An intriguing and highly successful collaborative model is the Fab Foundation, a not-for-profit movement founded in an educational outreach program by MIT in 2009 to facilitate the spread of a 'fab lab' network throughout the US and internationally, in partnership with corporate sponsors. The Fab Labs themselves, such as the one that Professor Marsh has visited in Berlin, utilize hands-on project-based digital fabrication, electronics and computation in an open, informal environment to bring the university's resources to the public to help

educate, upskill and inspire communities in STEM. Mobile Fab Labs look to take community manufacturing technology, such as laser cutters, 3-D printers and milling machines to more rural or disadvantaged areas.

With its strong history in manufacturing and the university's burgeoning reputation in engineering and robotics, Sheffield would seem an ideal leader in such collaborative partnerships to provide the curriculum development, skills training, outreach and effective public engagement that is needed to produce a workforce sufficiently skilled and accepting of robotics and AI to help the UK thrive in Industry 4.0.



RECOMMENDATIONS

There is the opportunity to establish a sustainable program of public engagement and outreach services, hands-on skills training, curriculum development and CPD in Robotics and Artificial Intelligence in line with the UK government's new Local Industrial Strategy and Digital Skills Partnerships program and building on the success of Sheffield and the AMRC as the UK's first digital innovation hub.

This programme can:

- Address and resolve the R&AI skills deficit with both formal and informal initiatives, on one hand developing formal teaching resources and methodology such as software, AR, MOOCs, course material and consultancy and on the other hand developing informal public engagement and outreach activities for community, adult, and after-school skills and awareness programs.

- Initiate and pilot a new public engagement and outreach program utilising Making and Makers to engage, inspire and demystify STEM, R&AI and new technologies. Robot Maker Centres could be opened in hub cities to attract people of all ages and backgrounds to informal, open-ended technology courses and interactive workshops. Robot Maker Buses could travel to remote community centres and libraries to reach more rural and disadvantaged communities. By scaling the program in this way, a significant national impact could be created on skills and education in robotics and AI.

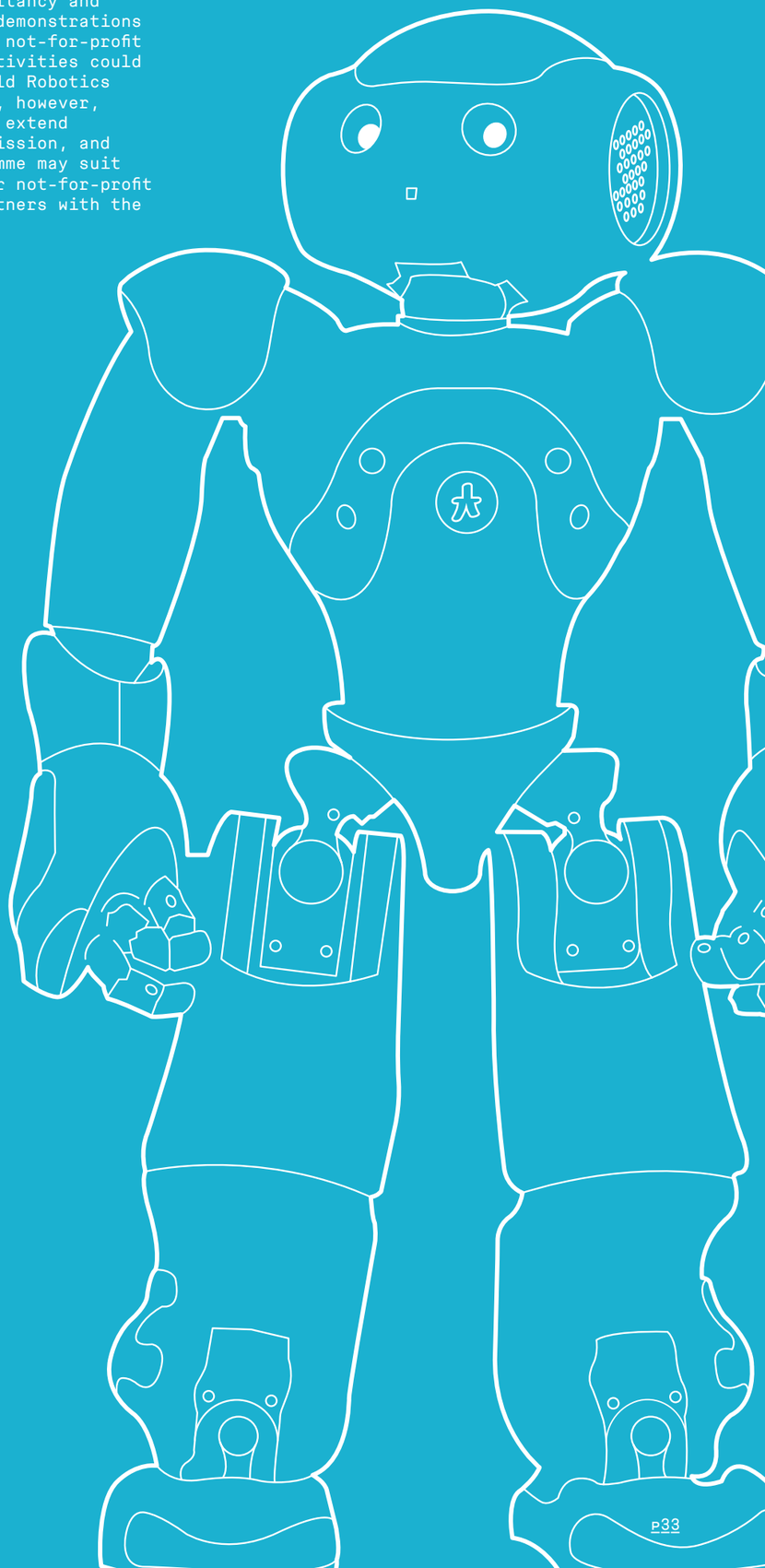
- Make Sheffield the first Skills and Education for R&AI (SERAI) hub in the UK while also developing other local partnerships based around universities and robotics centres to create a hub-based public training and outreach network throughout the UK.

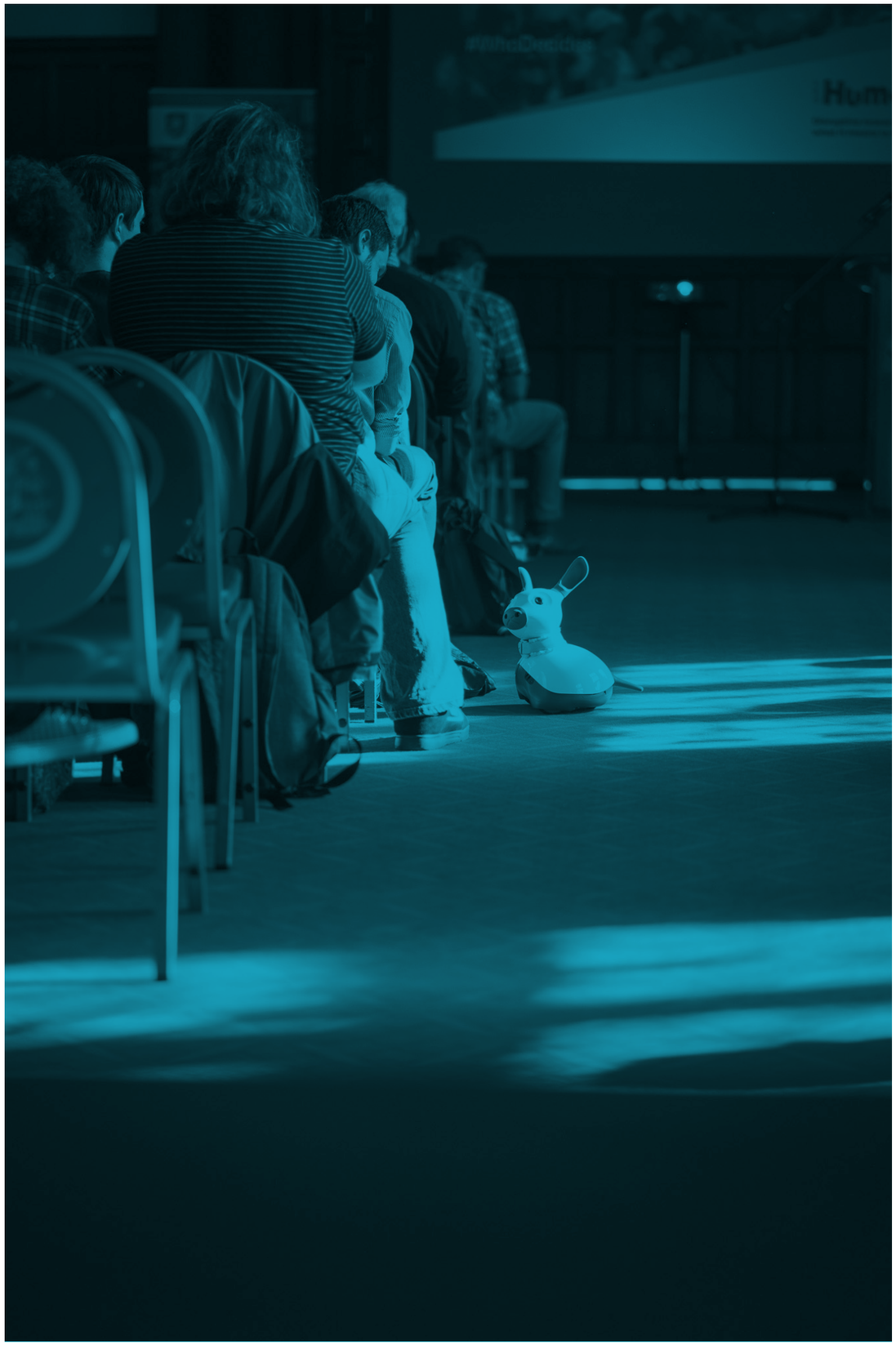
- Develop and maintain strong relationships with potential partners, such as with the public engagement, outreach and Institute of Coding teams at the University, the eLearning team at Sheffield City Council; Sheffield Digital, the national STEM Centre; the Micro:bit Foundation; AMRC; and with outstanding Sheffield technology companies such as leading 3-D and software developer Autodesk; and Pimeroni, the UK's second-fastest growing manufacturing company.

- Generate strong positive publicity for R&AI with a concerted campaign of podcasts and live webcasts, films and press releases to counter the often negative portrayal of R&AI in the mainstream media and to encourage more women and young people into new technology careers.

- Continue and expand the highly successful work of the AHRC-funded Cyberselves project, to encourage acceptance of R&AI and familiarise more communities with new technology by utilizing Sheffield Robotics' resources to engage, entertain and educate people in the potential of R&AI. Livestream broadcasts from Cyberselves events and continue generating positive publicity with blogs and press releases. Attending corporate functions and events could help make SERAI sustainable, while developing a SEND program, piloting the use of social robots such as MiRo in SEND schools, would extend the reach of SERAI's skills initiative.

Such an initiative could be supported by grant income; licensing; consultancy and training fees; and with robot demonstrations and exhibits for for-profit and not-for-profit organisation. Some of these activities could be operated in-house by Sheffield Robotics and the University of Sheffield, however, the broader aims discussed may extend beyond the University's core mission, and therefore parts of this programme may suit the formation of a for-profit or not-for-profit spin-out organisation that partners with the University.





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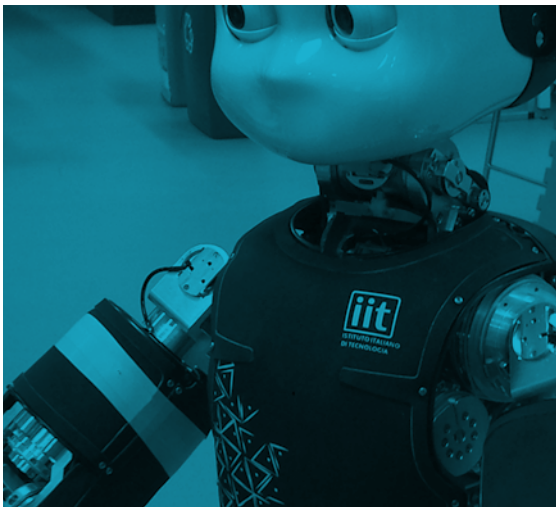
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