Robotics – Training for the New Age

European Survey Report

Robotics/AI and 3D printing

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In memory of Dr Tony Pustovrh (1979-2017) both a colleague and friend to us all.

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1. INTRODUCTION

The ERASMUS Plus project ROTENA: Robotics for the New Age aims to use the motivational effects of robotics and 3D printing to excite students and learners about science and to develop programmes to enable them to productively engage in the "New Age Technology" revolution. The development of an entry-level general robotics/3D printing curriculum should enable learners to acquire skills and competencies to understand the principles of robotics and 3D printing and their widespread application in industry in order for them to access jobs in these new-age industrial sectors. Robotics is a fast developing market increasingly driven by the development of novel and improved products in areas as diverse as manufacturing, search and rescue and retrieval, inspection and monitoring, surgery and healthcare, homes and cars, transport and logistics, agriculture, and many more. The rapid increase in the use of robots in our homes and at work, in hospitals and industrial environments provides an inspiring vision about how they can benefit society as a whole and how priorities to stimulate robotics should be defined at this point in their evolution, to best develop the potential for growth, jobs and innovation in Europe. Similarly, 3D printing offers many novel opportunities in architecture, construction, industrial design, automotive, aerospace, military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewellery, eyewear, education, geographic information systems, food, and many other fields. Transformative changes and new opportunities are expected in industrial and entrepreneurial ecosystems.[1]

In order to build on a solid empirical foundation, the first part of the project was dedicated to an extensive analytical exercise. The analysis was intended to take into account the current socio-technological context in which new technologies are opening new opportunities for industry, entrepreneurship and jobs, with a specific view to robotics and 3D printing. This includes new opportunities for both education and employment in these fields, as well as the skills that will be needed by prospective workers. As informatization and automation are expected to produce changes and even make some jobs obsolete while opening up new workplaces, it is important to motivate and engage people now so that labor market shortages for new age technology jobs will be minimal. Ensuring a sufficient number of skilled workers is also crucial to boost entrepreneurship and innovation opportunities in the fields. In this regard, existing workers should also be provided with opportunities to learn about robotics and 3D printing in order to help companies secure new markets and opportunities.

The first part of the analysis covers an overview and synthetization of what robotics and 3D printing, which are extensive fields, encompass for the purposes of the ROTENA project. The second part focuses on a benchmarking exercise and data collection activity that provides an overview of what entry-level, easily accessible courses on robotics and 3D printing are available in both Europe and internationally, identifying the best practices and strategies that training courses and education and training provider institutions should adopt to encourage such training, in short, providing examples and characteristics of best practices. Since educational and vocational training institutions are usually slow to adopt to technological and socioeconomic changes, knowing the current state of the art is necessary for the development of suitable training programs. The third part focuses on the results of an online survey, conducted among the three key stakeholder groups relevant for the purposes of the

[1] http://rotena.eu/

project: SMEs in the technology sector that will potentially take advantage of robotics and 3D printing to open new opportunities and secure a competitive advantage, as well require workers skilled in those fields; individuals who are potentially interested in engaging with and training in new age technology fields in order to become skilled workers and secure their employment the emerging sectors; and education and training provider institutions, who could be interested in making use of the entry-level curriculum for robotics and 3D printing, and adapting it to suit their own needs and characteristics, thus supporting industrial, entrepreneurial and innovative developments and meeting new training demands.

2. MODERN SOCIETY AND TECHNOLOGY

Looking at the overall picture, we could claim that technology in a general sense is a key factor in the socio-cultural development of humanity. It serves as a means of expanding the range of human capabilities, and it is also an element in a feedback loop within which technology, humans and society (and of course, the wider environment) mutually shape and transform each other.[2] New technologies, as far back as writing and the plow, and all the way forward to smart computational devices and automated production machinery, have brought new opportunities for production, transport and organization. They have also transformed the ways in which society is organized, including work processes, human interactions and social stratification. As humans are not born with an innate knowledge of how to operate specific technologies and how to efficiently conduct work processes, this requires the acquisition of specific knowledge, of skills, training and mastery in order to be able to occupy a specific job. In the scope of industry, economy and the allocation of work, this also means that specific jobs requiring specific capabilities, knowledge and skills will be more sought after and that others will be in much lesser demand. And as smart technology is increasingly able to automate at least some tasks, some professions and workplaces will become obsolete.

Technological development over the past two decades has been progressing extremely rapidly in several domains, especially in Nanotechnology, Biotechnology, Information-communication technology and Cognitive science (NBIC).[3] New technologies, especially those that are emerging at the intersections of the NBIC domains, are now permeating practically all levels and spheres of societies in the developed countries. Technological applications thus increasingly condition and mediate how we do things, that is, how we interact, how we think, how we produce and also how we learn and how we work. Contemporary societies are generally marked by a trend of acceleration, which means that, in no small part due to scientific and technological advances, things are changing more and more rapidly, whether we are talking about institutions, social interactions, technologies, jobs, employment, job opportunities, grand societal challenges and a score of others.[4] Another accompanying trend is a general orientation and striving to increase and enhance performance, both at the individual and the collective level, which is especially relevant in terms of job requirements, skills, performance and demands.[5] From an individual viewpoint, since the preconditions for living a fulfilling life in contemporary capitalist societies mostly still entail performing some sort of work that is compensated by a preferably high salary at a stable job, it is extremely important to have the necessary skills, know-how and experience to be able to compete for and enter such jobs. From a collective, societal perspective it is necessary to ensure that qualified workers are available to fill the demands for jobs

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[2] Laland, Kevin N. and Michael J. O'Brien. 2011. Cultural Niche Construction: An Introduction. *Biological Theory* 6(3), 191–202.
Kendal, Jeremy, Jamshid J. Tehrani and John Odling-Smee. 2011. Human niche construction in interdisciplinary focus. *Philosophical Transactions of the Royal Society London B Biological Sciences* 366(1566), 785–792.

[3] Roco, C., W.S. Bainbridge (Eds.). 2003. Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. Dordrecht: Springer.
Bainbridge, William Sims in Mihail C. Roco, ur. 2005. Managing Nano-Bio-Info-Cogno innovations: Converging Technologies in Society. Dordrecht: Springer.

[4] Rosa, Hartmut and William E. Scheuerman. 2008. High-Speed Society. Social Acceleration, and Modernity. Penn State University Press.

[5] Coenen, Christopher, Mirjam Schuijff, Martijntje Smits, Pim Klaassen, Leonhard Hennen, Michael Rader, and Gregor Wolbring. 2009. Human Enhancement. Brussels: European Parliament, DG Internal Policies STOA.
Fuller, Steve. 2013. Preparing for Life in Humanity 2.0. Palgrave Macmillan.

that are opening due to new developments and new opportunities, and that are connected with addressing societal challenges, needs and wants.[6]

The current societechnological context in which modern, technological capitalist societies are currently located, is strongly marked by technological innovations, which, together with rapid sociocultural transformations, are producing rapid shifts and changes in all spheres of society. For the scope of this report, we will primarily focus on the areas of education, training, employment and skills that are needed to access new and emerging jobs in what we, for the purposes of the ROTENA project, have termed New Age Technologies. But in order to better understand what is going on, we should first take a look at the technological side.

Societies, which are increasingly interconnected through globalization and information-communication technologies, are currently being strongly affected by several technological trends, among which are, in a general sense, digitalization, automation and robotization. All these trends are of course mutually interconnected and are enabling and reinforcing each other. Digitalization is visible in terms of the widespread introduction of various digital technologies in the work process, planning and monitoring.

Many workplaces are now becoming **digital workplaces**. Automation means that a number of tasks in the workplaces, and in some instances entire work processes, can be carried out by smart machines, with little or no human supervision and input. This can relate either to industrial manufacturing, to warehouse robots, or to data acquisition, analysis and management. Robotization refers to physical manipulators, at least partially controlled by some form of information technology, that carry out various work tasks or processes by manipulating objects in the physical environment, either semi-autonomously or completely autonomously. Thus, increasingly smart machines are able to carry out not just predictable physical activities but also more demanding cognitive activities.

Some experts postulate that we are currently located in the midst of a new industrial revolution, what Brynjolfsson and McAfee term as The Second Machine Age[7] or what others have called The Fourth Industrial Revolution or Industry 4.0.[8] While the First Machine Age was marked by the automation of physical tasks through mechanization, the second is characterized by the automation of cognitive tasks through digital technologies. The progress in the development of the underlying enabling technologies is exponential, the technologies are mostly digital and are driving the digitalization of previously solely physical objects and processes, and they are capable of combinatorial reinforcement, meaning that robots can be directed through cloud-based algorithms, that tasks and needs can be automatically communicated through networks without human intervention, that digital objects can be printed remotely using 3D printers, and that big-data driven analytics can be used to optimize drug discovery or disease prediction. Similarly, in Industry 4.0, various technologies are combining and blurring the boundaries between the physical, the digital and the biological. The third industrial revolution made

[6] Von Schomberg, René. 2013. A vision of responsible research and innovation. In: Owen, Richard; Bessant, John; Heintz, Maggy: Responsible Innovation. Managing the responsible emergence of science and innovation in society. London: Wiley, 51-74.
Stilgoe, Jack; Owen, Richard; Macnaghten, Phil. 2013. Developing a framework for responsible innovation. Research Policy 42, 1568-1580.
European Commission. 2012. http://ec.europa.eu/research/science-society/document_library/pdf_06/responsible-research-and-innovation-leaflet_en.pdf
https://www.rri-practice.eu/about-rri-practice/what-is-rri/

[7] Brynjolfsson, Erik and Andrew McAfee. 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. W. W. Norton & Company.

[8] Schwab, Klaus. 2016. *The Fourth Industrial Revolution: what it means, how to respond*. World Economic Forum. https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

use of electronics and information technology, in the forms of computer and automation, to achieve further automation, while the fourth industrial revolution is based on cyber-physical systems that are increasingly connected and smart. Their distinctive features are that the speed of their progress is exponential, that their scope is widening, as they are being disruptive in a growing number of industries globally, and that they are having a systemic impact, for example on production (workplaces), on management (organizations, companies) and on public policies (economy, employment, education).

There are numerous technology fields and technological applications that are likely to have disruptive impacts in the coming years and decades. Both the expert literature and the media are full of speculations how the internet of things, 3D printing, social robots, artificial intelligence, expert systems, smart personal assistants, self-driving cars, quantum computers, robotic exo-skeletons and other features that were once only in the domain of Science Fiction, will transforms our lives and societies. For the purposes of the ROTENA project, we have focused on two technologies, which we identify as having the greatest potential and urgency in terms of new opportunities for work and employment, impacts on industry and entrepreneurship and a societal need for students and workers both interested and skilled in their production and operation. The two technological fields we focus on are robotics and 3D printing. Before we take a look at the various projected impacts these two technologies will or might have across industry, work, education and other spheres, we should first define at what we want to include under these two terms.

3. DEFINITION OF ROBOTICS AND 3D PRINTING

3.1 Robotics

A condensed definition for the purposes of the ROTENA project

Robotics is a multidisciplinary technoscience that combines mainly mechanics, electronics and computer science. Its goal is the research, design, development and building of robotic systems controlled by integrated circuits. ROTENA Partners see the learning and use of Robotics as a way to develop the skills that will allow people to build autonomous projects that will contribute not only for personal and professional development, but also for innovation and entrepreneurship. The knowledge acquired in this field will make the users technologically adaptable in a fast changing society.

What is robotics?[9]

In general, we can think of **robotics** as a multidisciplinary science and technology field or approach, where the goal is to research, design, develop and build various **robotics systems and robots**, including their programming, operation, usage and maintenance. As with many new technologies that are experiencing rapid growth, it is not easy to strictly define and separate different concepts, objects and fields. **Robotics** can be conceptualized as an expanding research and technology field that combines various disciplines, including mechanical and electronic engineering and computer science as the core disciplines, but there is increasing cross-fertilization and convergence with various other fields such as biology, materials science, cognitive neuroscience, etc. The rapid development, cutting edge technology, multidisciplinary and its converging nature make robotics education quite challenging.

A robotic system or robot can be defined as a machine that is designed on the paradigm of "sense-think-act", meaning that it is programmable, can sense its environment, respond and manipulate the environment. As such, the robotic system has three key components, namely sensors to monitor the environment, a programmable controller (processors, AI) to decide on the responses, and actuators or

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[9] A Roadmap for US Robotics: From Internet to Robotics. 2016 Edition.
Gerhard Schweitzer, ETH Zurich, HUT, 8092 Zurich, Switzerland, 17th International Congress of Mechanical Engineering (COBEM 2003), São Paulo, Brasil, November 10-14, 2003 (Invited Paper)
Benjamin Wittes and Gabriella Blum. 2015. The Future of Violence: Robots and Germs, Hackers and Drones—Confronting A New Age of Threat. New York: Basic Books.
Peter Sinčák, Pitoyo Hartono, Mária Virčíková, Ján Vaščák and. Rudolf Jakša. 2014. Emergent Trends in Robotics and Intelligent Systems: Where Is the Role of Intelligent Technologies in the Next Generation of Robots? Cham Heidelberg New York Dordrecht London: Springer.
Encyclopædia Britannica. 2016. Robotics. Available at: https://www.britannica.com/technology/robotics.
Oxford Dictionaries. 2016. Robotics. Available at: https://en.oxforddictionaries.com/definition/robotics
LEO - Center for Service Robotics. 2016. Defining robots and robotics. Available at: http://www.leorobotics.nl/definition-robots-and-robotics
NASA – National Aeronautics and Space Administration. 2016. What Is Robotics? Available at: http://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-robonaut-k4.html.
Maja J Matarič. 2007. The Robotics Primer. Cambridge, Massachusetts London, England: The MIT Press.
Andreas Birk. 2011. What Is Robotics? An Interdisciplinary Field Is Getting Even More Diverse. IEEE Robotics & Automation Magazine, December 2011.
http://www.revereschools.org/cms/lib02/OH01001097/Centricity/Domain/64/VEX%20Robotics%20Unit%202-Intro%20to%20Robotics.pdf
ACCA (the Association of Chartered Certified Accountants). 2015. The robots are coming? Implications for finance shared services. Available at: http://www.accaglobal.com/content/dam/ACCA_Global/Technical/fin/ea-robots-finance-shared-services-0909.pdf.
Stefano Nolfi and Dario Floreano. 2004. Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines. Cambridge: MIT Press.
www.directrecruiters.com/wp-content/uploads/.../Robotics_4-16.pdf

effectors to act on the environment (movement and/or manipulation). In a nutshell, the robot can be seen as a fusion of a machine and a computer. The robot is usually made up of mechanical and electronic components, although there are also experimental hybrid/biological robots and virtual (digital) robots. For the purposes of this definition, the robot must exist in the physical world and be able to influence it.

While some robots are built for the research purposes of testing aspects of behavior and cognition in intelligent agents such as human and non-human animals, the general purpose of building robots is to (partially or fully) automate tasks and processes that were previously performed by humans. Sometimes it is difficult to distinguish between what we would consider a "true" robot (e.g. NAO) and an automated, fixed piece of robotic machinery (e.g. conveyor belt). In that sense, a robot needs to be capable of some minimal **autonomy** in order to be considered a robot. Here, we should also note that the category of what is considered a robot changes with time and technological development. Machines are more likely to be deemed robots if they have some humanoid features (arms, legs, head, mobile base), and if they can mimic some types of human physical or cognitive capabilities and behaviors (movement, speech, adaptability).

Both robotics and robots are closely connected with the concepts and fields of **automation** and **artificial intelligence**. **Automation** focuses on systems that can operate autonomously, without constant human supervision, and emphasizes efficiency, productivity and reliability with minimal human intervention (e.g. factory production and assembly lines). **Artificial intelligence (AI)** is both a scientific and technology field, and in this context can be seen as the software necessary to control the robot's responses and increasingly enable the capacity to emulate aspects of biological cognition, such as perception, sensorimotor navigation, memory, etc. Although some AI can exhibit specialized intelligence in narrow domains (search engines, playing games, big data informatics, medical diagnosis, etc.), the goal of artificial general intelligence that would equal or surpass human intelligence is still a distant effort. Greater (specialized) cognitive and physical autonomy can be seen as a general goal of AI. Ultimately advances in both AI and robotics hardware are necessary to increase the **autonomy**, as the capability for unsupervised operation, and range of capabilities of future robots.

While increasing progress in the sophistication of both the hardware and the software is enabling the development of robots that come in all shapes and sizes, from somewhat humanoid to insectile, able to perform a variety of tasks and functions, the main differentiation regarding operational capability is into narrower, specialized automated robotics systems and into more flexible, adaptable, smart robots. The first category is primarily focused on **automation**, especially in terms of increasing efficiency, speed, productivity and quality of specialized systems in a controlled, predictable environment (e.g. factory, laboratory). The second is primarily focused on developing greater autonomy and adaptability through intelligent (AI-driven) responses in more complex, less predictable environments (e.g. shopping mall, apartment). The latter should be capable of a greater range of various tasks performed in different environments, and of increasingly learning from past experiences.

Ultimately, a robot should be capable of autonomous and purposeful sensing and acting and achieving goals in the physical world. Whether or not we would consider a drone, a roomba floor cleaner or a self-driving car a robot depends on what degree of autonomy, decision-making and adaptability, but on the other hand also body shape, we consider to be essential robot characteristics.

A brief history

The basic ideas of robotics and its potentials have been present in the human imagination for much longer than the field has existed as an engineering approach and a technoscientific field. The ideas of automata that can mimic, perform or take over functions and tasks originally performed by humans or animals goes back to ancient mythologies, with Greek mechanical servants, Jewish golems, Nordic clay giants and Buddhist and Chinese mechanical humanoids. There are also many accounts of ancient inventors and engineers building self-operating machines resembling humans and animals, such as birds, up to the industrial age, but they were mainly used for novelty and entertainment purposes.

The word robot was first introduced by Karel Čapek in his 1923 short science fiction play *Rossum's Universal Robots* (R.U.R.) about artificially created humanoids that are forced to perform labor for true humans and who eventually rebel against their masters. The Czech word for forced labour or drudgery is robota and this is where the now universal term robot originates. The term and concept was adopted in 1941 and then popularized by the prolific science fiction author and scientist Isaac Asimov (and later others) in his many stories and books on electromechanical robots that could take on most human tasks, which inspired engineers and researchers as well as the popular imagination and media.

While the first mechanical humanoid robots were showcased from the 1930s onward, George Devol invented the first digitally operated and programmable robot in 1954, Unimate, laying the foundations for the modern robotics industry. Unimate was sold to General Motors and installed in a plant in 1960, to lift hot metal pieces and stack them. The Fuji Yusoki Kogyo Company introduced the first palletizing robot in 1963. From then on, robotics systems and robots progressively became more skillful, mobile, programmable and equipped with sophisticated sensors. While much of science fiction, movies and the popular imagination up to the 1990s conceived of the future of robots as general-purpose devices in more or less humanoid form, the practicalities and complexities of robotics and AI design are currently indicating that it is more likely that many different types of more or less specialized robots will become widespread in both industry and everyday life.

Given the large potential and expectation about the development, use and maintenance of robotics systems and robots, we can see that there is also an emerging need for people who are interested in studying and skilled in working in such areas. The current educational curricula are mostly not prepared for the emerging need for such talent in industry and SMEs. As we have illustrated, due to the complex, multidisciplinary and converging nature of robotics it is also difficult to acquire talent with the specific skills and backgrounds needed. The purpose of ROTENA is based around motivating and empowering young people and aspiring learners to become both acquainted and motivated to engage with introductory robotics and learn the basics that will enable them to learn the basic skills necessary to build and program a simple robotics system. ROTENA also advocates a hands-on, practical approach in learning, which is why we are enthusiastic about the use of commercially accessible robotics learning sets such LEGO mindstorms. With the first step of becoming interested and learning introductory robotics, we hope to motivate individuals to further pursue and develop their skills, knowledge and interest in the area of robotics and associated fields, which will make them better equipped to participate in and co-create the emerging economy that will be powered by New Age Technologies.

3.2 3D printing

A condensed definition for the purposes of the ROTENA project

3D printing refers to the process of additively building a three-dimensional physical object from a digital model data (Computer Aided Design or scanned object) file by depositing and forming successive layers of material under computer control.

What is 3D printing?[10]

In a nutshell, a 3D printer is a machine that can turn a blueprint into a physical object by applying material layer by layer without the need to adjust the production tooling. 3D printing refers to the process of additively building a three-dimensional physical object from a digital model data (Computer Aided Design or scanned object) file by depositing and forming successive layers of material under computer control. This additive manufacturing process is the reason why 3D printing is also referred to as "additive manufacturing", and while technically more accurate, the term 3D printing has been more enthusiastically adopted due to mainstream media difussion. The analogy with document printing also plastically presents the basic underlying concept of depositing material with a printing head in order to bring a specified object into existence. However, there are many underlying additive manufacturing technologies that can be used (e.g. stereolithography, laser sintering, fused deposition modeling), which allow various degrees of precision and sophistication. While in principle the printed objects can be of almost any shape or geometry, their characteristics depend on the underlying printing technology and the materials that can be employed. With advanced 3D printers it is also possible to create assembled objects with internal, movable parts. The time it takes to print a full object however increases with the level of detail and complexity of the object.

The technology is significant because it offers direct manufacturing, meaning a design goes directly from designer to physical product through a computer and a 3D printer. It brings a revolutionary approach to manufacturing through three key advantages - shorter lead time, design freedom, and lower costs. It thus enables rapid and low-cost prototyping, manufacturing end-use products (direct digital manufacturing) and producing tooling that allows the manufacture of other components and products using different methods.

In ROTENA we see the (introductory) knowledge and (basic) use of 3D printing as a tool that can motivate, enable and empower. In terms of motivation and inspiration, it allows the user/learner to experience a rapid and easy materialization of the envisioned objects, it enables the production of parts that can be used in robotics training and ultimately empowers the user to master the skills that will be relevant and needed in the field of New Age Technologies. Finally, it can be used to foster

[10] http://3dprinting.com/what-is-3d-printing/
https://www.stratasysdirect.com/resources/what-is-3d-printing/

Bandyopadhyay, Amit and Susmita Bose (Eds.). 2016. Additive Manufacturing. Boca Raton, London, New York: CRC Press Taylor and Francis Group.

van den Berg, Bibi, Simone van der Hof and Eleni Kosta (Eds.). 2016. 3D Printing Legal, Philosophical and Economic Dimensions. The Hague: TMC Asser Press.đ

Goodship, Vanessa, Bethany Middleton and Ruth Cherrington. 2016. Design and Manufacture of Plastic Components for Multifunctionality: Structural Composites, Injection Molding, and 3D Printing. Oxford, Waltham, MA: William Andrew, Elsevier.

Gibson, Ian, David ¬Rosen and Brent ¬Stucker (Eds.). 2015. Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing 2nd Ed. New York Heidelberg Dordrecht London: Springer.

Muthu, Subramanian Senthilkannan and Monica Mahesh Savalani (Eds.). 2016. Handbook of Sustainability in Additive Manufacturing, Volume 1. Singapore: Springer Science+Business Media.

Birtchnell, Thomas, and William Hoyle. 2014. 3D Printing for Development in the Global South The 3D4D Challenge. Palgrave Macmillan UK.

creativity, innovation, experimentation and a DIY, maker mentality that can be usefully employed in an entrepreneurial as well as an industrial setting.

There are also enabling interconnections between the fields of robotics and 3D printing, for example printing robot parts with 3D printers, such as engineers would be unable to construct otherwise. Such an example is a soft legged robot that can navigate difficult terrain and could be used in search and rescue operations.[11]

[11] http://www.bbc.com/news/av/technology-40296297/the-soft-3d-printed-robot-that-could-come-to-the-rescue

4. IMPACT OF ROBOTICS AND 3D PRINTING ON INDUSTRY, WORK, EDUCATION AND SOCIETAL NEEDS

Usage and applications of robotics

There are many predictions regarding how the trends in robotics and 3D printing will continue to develop and impact specific industries, workplaces and practices, as well as education and societal needs and structures. Most existing robots are currently used in industrial manufacturing. The total worldwide stock of operational industrial robots at the end of 2015 was about 1.6 million units and the value of the global industrial robotics market was US$11 billion in 2016, while the robotics systems market (including software, systems engineering, etc) is estimated at US$35 billion. [12] Of the existing industrial units, 272,000 were in America (259.200 in North America), 914.000 are in Asia and Australia (262.900 in China, 297,200 in Japan 201,000 in South Korea). Europe had 433,000 (183,000 in Germany). Africa had 4,500. In 2016, 290,000 new robots were installed globally. The majority of such robots are used in the automotive and the electrical/electronics industries, followed by metal, chemical and food industries. The average global robot density is about 69 industrial robots installed per 10,000 employees in the manufacturing industry in 2015. The most automated markets are South Korea, Singapore, Japan and Germany. The US, one of the biggest robot markets has a robot density of 176 units in 2015, and China, the biggest robot market since 2013, reached 49 units in 2015, showing huge potential for robot installations. In 2015, about 5.4 million service robots for personal and domestic use were sold, 16% more than in 2014. The value of sales increased by 4% to US$2.2 billion.[13]

Projections for new installations in 2019 are 50,700 for America (46,000) North America, 285,700 for Asia and Australia (160,000 in China, 43,000 in Japan, 46,000 in South Korea). For Europe, the projections are 433,000 (25,000 in Germany), and for Africa 800. The global robot market between 2016 and 2019 projections are that 1,4 million new industrial robots will be installed in factories, 333,000 will be sold to both the industrial and non-industrial sector and 42 million service robots for personal and domestic use (consumer robots) will be used privately. While the sale of robot companions/assistants/humanoids has been quite low until now, it is projected that between 2016 and 2019 some 8,100 units of these robots will be sold. This clearly shows that there will be future labor demand for people who design, produce, maintain, program and operate robots.

Much of the current R&D efforts in robotics are aimed at developing more sophisticated robots for the non-industrial domain, including the healthcare and medical (hospital, care facilities), service (homes, hotels), space and military sectors. In this regard, there are large development and economic expectations regarding household robots, robots that can assist the assist the elderly and infirm, robotic systems for medicine and surgery, for use in agriculture[14] and surveillance, in space and sea exploration, military robots, robots for education[15] and entertainment, companionship, fast food servers and cooking, as well as hotel receptionists. Such robotics systems are increasingly equipped with sophisticated AI, increasing self-sufficiency that permits mobility and decision-making in more

[12] International Federation of Robotics 2016

[13] World Robotics Service Robots 2016 https://ifr.org/free-downloads/

[14] http://www.bbc.com/news/business-38089984

[15] http://www.bbc.com/news/technology-38758980

complex and unpredictable environments, with basic learning, flexibility and robustness. While industrial robotics will remain the largest market, the non-industrial domain is expected to experience a large robotics boom in the coming decade.

Today we are seeing robots of various forms performing many different tasks, although most remain in the domain of industrial manufacturing, usually performing repetitive, predictable, difficult and highly specialized tasks. Nevertheless, we are seeing automated and semi-automated robotics systems used in surgery (e.g. the da Vinci surgery system),[16] for telepresence in hazardous environment (the huge explosion of commercial drones, probes on other planets, in the sea), and we now have robots available for domestic consumer use, for example vacuum cleaners and washers, lawn movers (e.g. Roomba). We are also seeing the first automated robotics systems preparing food in fast food restaurants,[17] or performing the work of receptionists in hotels, and the first self-driving cars have successfully completed various routes, along with an Uber self-driving 18-wheeler truck delivering a cargo of Budweiser beer.[18] A parallel research goal is however still to develop robots that can perform a wider range of human-like capabilities.

Usage and applications of 3D printing

Similarly, 3D printing or additive manufacturing is a technology that has been in the making since the latter part of the 20th Century, but has only now reached a point of technological development where it is becoming accessible to

Commercially, these technologies are predominantly used in high value-added industries and applications including those involved with aerospace, automotive, and biomedical (prosthetics and implants) products which require highly complex and customized designs at low volumes. Still, improvements in terms of speed, accuracy, material properties, machine reliability, and development of low-cost machines has widened the accessibility and user base, and thus holds great potential. Currently, just one in a thousand products is fabricated using 3D printing. Global manufacturing was worth $10.5 trillion in 2011 and is predicted to be worth $15.9 trillion in 2025. The 3D printing economy was worth $1.7 billion in 2011 and is estimated to be worth $10+ billion by 2025.

Low cost, basic 3D printers for universities, schools, laboratories, DIY and maker communities offer many benefits in terms of promoting research and interest in design, engineering, technology and manufacturing, as well as in terms of promoting crafts, experimentation, creativity, curiosity and innovation. While 3D printers are not yet widely diffused and printing complex objects with various materials through moderately priced printers is still at least some years off, sophisticated printers are becoming accessible to smaller businesses and private individuals, where they can be employed to test and develop new products, ideas or designer items.

The concept and technology of 3D printing also presents new business opportunities as well as new (including social) entrepreneurial models based on transforming digital data into physical objects in remote locations, independent of centralized production and industrial areas by using "printing hubs". In addition to enabling the creation of a greater range of products than would be possible with conventional manufacturing, it presents the possibility to democratize design and empower communities by decentralizing production, and promoting innovation and creativity. Making product

[16] http://allaboutroboticsurgery.com/surgicalrobots.html
[17] https://singularityhub.com/2017/03/08/new-burger-robot-will-take-command-of-the-grill-in-50-fast-food-restaurants/
[18] https://www.wired.com/2016/10/ubers-self-driving-truck-makes-first-delivery-50000-beers/

conceptualization, creation and propagation possible in any (relatively speaking) geographical location or community, makes 3D printing businesses and jobs potentially less vulnerable to off-shoring. All this of course also raises issues of intellectual property rights and environmental impacts resulting from possibly increased consumption and production in vulnerable, remote locations, etc.

From a sustainability viewpoint, it could reduce environmental impacts through lower waste and reduced need for transportation, as well as enable greater sociopolitical independence and empowerment through decentralization and inclusivity in of production and inclusivity. It also has the potential to improve sociocultural sustainability (retaining social and cultural diversity) by supporting communal and individual designer-makers. It could increase their economic viability, providing an effective mechanism for craftsmen to compete in a global market utilizing local 3D print manufacturing, increasing geometric and material complexity, and the ability to customize products.

Impacts of robotics and 3D printing

In general, robots offer considerable economic benefits to companies and employers, also in terms of lower labour costs, as robots do not require healthcare, annual leave, health and pension security or other social benefits. Regarding production and work, they enable increased productivity, faster speeds, greater precision, lower costs and an expansion of work beyond the current range of human capabilities. As robotic systems become more sophisticated and their price begins to drop, this would also mean that they present an increased scope of innovative activities achievable by SMEs. As robotics systems become more sophisticated, we can expect that more businesses will have to adopt robotic systems in order to stay competitive and innovative in the increasingly interconnected global market.

When it comes to the adoption of robots, not only industry readiness is important, but so are public attitudes. Especially when it comes to service robots that interact with customers or patients and robots that are intended for private and domestic use, familiarity and positive public attitudes can strongly influence adoption and successful usage. A 2012 Special Eurobarometer Survey on Public Attitudes Towards Robots[19] found that a majority of EU citizens have a positive view of robots, which varies by country, with percentages ranging from 54% in Greece and Malta to 88% in Denmark and Sweden. On the one hand they see the use of robots in some jobs as useful and positive, for example in space exploration (52%), manufacturing (50%), military and security (41%) and search and rescue tasks (41%). On the other, there is wide agreement that they should be banned in the care of children, the elderly or the disabled (60%). Large majorities also prefer a ban in areas such as education (34%), healthcare (27%) and leisure (20%). Thus opposition is strongest in areas where it comes to more intimate and important connections between humans and robots, and where the human subjects are vulnerable or underage. Most were uncomfortable with the idea of a robot caring for their elderly parents, children or dog, or performing a surgery on them. Interestingly, most EU citizens were relatively comfortable about the idea of a robot assisting them at work. Taking all this into account, we can see that communicating both the benefits and the risks of introducing robotics and 3D printing into society is another important component of ensuring a successful societal adoption of such technologies.

There are large technological, economic and societal expectations regarding future developments in industrial and non-industrial (service, private-use) robotics. As we have seen above, many new robots

[19] Public Attitudes Towards Robots. Special Eurobarometer Report. 2012. http://rotena.eu/Public_Attitudes_to_Robots.pdf

and robotics systems are in development, there are many new laboratories and research groups, and much is expected of advances in AI. What is expected are better, more precise and cheaper procedures in medicine, telepresence usage in remote areas, reduced costs and better products enabled by more automated industrial manufacturing.

Some of the expectations are that robotic systems will do more of the work in factories and that advances in self-driving vehicles will lead to more or less automated transportation. Industrial robotics could eventually enable "dark factories", where the need for human supervisors and intervention is minimal, and more optimized transport, which would also mean lower environmental impacts. As the production of robots itself becomes an expanding industry, along with maintenance and programming, this might mean more high-skill jobs in the developed countries, similar as with expectations regarding the decentralized manufacturing potential of the emerging 3D printing industry and capabilities. Of course, this over the long run again becomes potentially vulnerable to off-shoring with more competitive (lower) wages, more permissive work and environmental regulation, etc, and as many other questions of national interest becomes an issue of who will build and maintain the robotics systems that the emerging market will demand.

The introduction of new machines that automate tasks previously performed by humans or animals has also been accompanied by the fear and actual loss of work and jobs since at least the industrial revolution and the now famous Luddite struggles against work loss due to industrial looms introduced in 19th Century England. Thus the positive impacts of increasing automation and robotization, especially in the industrial and commercial sectors, are always accompanied by the societal side-effect of the reduced need for human workers, whose occupations are often made obsolete. Although there are always new jobs that are created because of the introduction of new machines and technologies, usually more skill-intensive, the question of how to retrain the now unemployed and whether enough and what kind of jobs will always be created to replace even white-collar workers and experts, remains open.

Some recent studies from prestigious institutions, for example the one conducted by Oxford University and Deloitte predict a high probability that 47% of 700 jobs in the USA will be automated within the next 10 to 20 years[20]. In the UK, about 35% of current jobs are at high risk of automation by 2030.[21] Further studies have predicted that about 57% of jobs in the OECD will likely be automated, with probably 69% in India and 77% in China[22]. The McKinsey Global Institute predicts the potential automation of half of the 2,000 current work activities in 800 jobs by 2055 on a global scale. This means that there will be changes in a majority of jobs, which will require new skills and knowledge, but that there will not be complete automation of most jobs. The jobs that are however most likely to be automated are those involving predictable physical activities (81%), data processing (69%) and data collection (64%). Thus it is not only low skill and low wage jobs that are vulnerable to full automation, but an approximately equal number of the lowest and the highest paying jobs.

[20] Frey and Osborne 2013

[21] http://www.bbc.com/news/business-39377353

[22] Citibank, Frey, Osborne 2016

There has been much debate on how to ensure that when automation, technological unemployment and obsolescence become widespread, people whose wages have declined or whose jobs have become automated, still receive a proper income. Two of the most widely discussed options to ensure a flow from automation profits back to consumers have been the introduction of a Universal Basic Income (UBI) and the introduction of a tax on robots. UBI[23] has been endorsed by many academics and also by some of the prominent figures in the field of technology and entrepreneurship, for example Elon Musk[24]. The latter sees it as a necessity to address the social inequalities that will be worsened by job loss and displaced through automation. Other prominent figures in Silicon Valley, such as the web guru Tim O'Reilly and venture capitalist Marc Andreessen have also stepped behind such ideas, and his Y Combinator will be conducting its own basic income experiment with a pilot study of 100 families in Oakland, California.[25] In simplified terms, UBI would be a fixed amount high enough to ensure subsistence, given by the government to all its citizens regardless of income or work status. It could take a variety of forms, among them as hose proposals can take a variety of forms, including universal grants, a negative income tax or a type of wage supplement. The revenue from robots and robotic systems is expected to be high, and diverting a portion of this into a form of UBI would ensure that consumers are still able to purchase the goods and services produced by automated systems.

The tax on robots who take human jobs was most famously proposed by Bill Gates.[26] This tax could be used to finance jobs for which human workers are best suited, and for which most surveyed Europeans think humans would be the best option - for example in the interaction with and care of children and the elderly. A further argument is that robot workers do not make use of services financed by tax revenue such as education or health and pension services. How this would be greeted by corporations, shareholders and investors that want to make a profit from the development and use of robotic services however remains an open issue. Gates acknowledges this and proposes that government would need an active role in establishing such a policy. One option would be to calculate the tax on the basis of a notional salary paid to the robot, and the company could deduct this notional payment for the purpose of corporation tax. Taxation would be done in the jurisdiction in which the robot is located. As people are becoming anxious about robots taking their jobs, taxation would be preferable to banning the use of robots in specific domains.

If we imagine the introduction of new types of robot workers into factories and especially automation of transportation, we are already talking about the potential displacement of large numbers of manufacturing workers and professional drivers. The Taiwanese Apple manufacturer Foxconn Electronics, for example, has announced a three part plan that would eventually lead to full automation, with hopes of achieving 30% automation by 2020.[27] In the US, for example, according to 2014 Census data, this could amount to more than 4.4 million Americans who are categorized as driver/sales workers and truck drivers.[28] Further mentioned advances target cleaning, hotel

[23] https://futurism.com/images/universal-basic-income-answer-automation/

[24] https://www.geek.com/tech-science-3/elon-musk-automation-will-force-universal-basic-income-1701217/

[25] https://www.theguardian.com/technology/2016/jun/22/silicon-valley-universal-basic-income-y-combinator

[26] http://www.businessinsider.com/bill-gates-robot-tax-brighter-future-2017-3

[27] https://futurism.com/apple-manufacturer-foxconn-to-fully-replace-humans-with-robots/

[28] http://www.cnbc.com/2016/09/02/driverless-cars-will-kill-the-most-jobs-in-select-us-states.html

receptionists, fast food workers and others, not to mention the jobs that will probably be lost due to advances in AI that is capable of wider pattern recognition (text, speech, search, analysis, etc). But not only jobs in developed countries are at risk. According to the International Labour Organization studies, about 56% of workers in Cambodia, Indonesia, the Philippines, Thailand, and Vietnam could be displaced by automation and advanced technologies, such as 3D printing over the coming decades.[29] On the positive side, there are also many emerging opportunities and much potential for SMEs and entrepreneurship, as developing innovative robotics applications and tools becomes more accessible through cheaper and more capable hardware and software.

The analyst Stuart Elliot, who posited in 2014 that about 80 percent of current jobs could be automated in the future, also writes that employment in the remaining 20 percent of jobs could be expanded to absorb the entire labor force.[30] Robots ultimately (still) need to be designed and created by humans.

The field of robotics traditionally grew out of mechanical and electrical engineering and computer science, and such expertise is still crucial as new jobs and challenges in robotics are emerging. In this regard, the areas of mechanics, control, perception, AI, cognition and systems will all require robotics and engineering talent in terms of work and research.[31] As many jobs increasingly require interaction and cooperation between robotic systems and humans in the workplace, experiences from the field of psychology, specifically in terms of human-machine interaction are another niche that is currently emerging. Prof. Vijay Kumar from the School of Engineering and Applied Science at the University of Pennsylvania lists six engineering degrees with a specialization in robotics offered across the US, while a degree in mechanical engineering could be the next best thing. Still, he posits that the most sought-after profiles will be programs that provide experiences across various disciplines, for example mechanical and electrical engineering and programming. In this regard, hands-on experience will also be of crucial importance. In this regard, robotics training kits such as Lego Mindstorms can be a good place to start, and for programming, embedded systems like Raspberry Pi are good choice. One of the best ways to get hands-on experience is to enter a robotics competition.[32] Another list defines the skill set a good roboticist should have as a combination of hard and soft skills.[33] This list includes systems thinking, a programming mindset, active learning, knowledge of mathematics, science or other applied mathematics, judgment and decision-making, good communication, technology design, complex problem solving and persistence.

The jobs that are currently open in the field of robotics are mainly in the automotive industry and businesses that already use robotics systems. Many startups are now focusing on developing new robotics systems, and here creativity and an open mind in addition to the other qualifications listed is needed. The Yasakawa company blog lists potential employment in jobs such as robotics technician

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[29] https://qz.com/727102/robots-are-set-to-take-the-jobs-of-millions-of-asian-workers-in-the-coming-years/

[30] http://issues.org/30-3/stuart/

[31] http://www.careerbuilder.com/advice/building-tomorrows-workforce-hot-jobs-in-robotics

[32] http://blog.robotiq.com/what-to-study-for-a-career-in-robotics

[33] http://blog.robotiq.com/10-essential-skills-that-all-good-roboticists-have

and robotics engineer,[34] along with other supporting and enabling jobs such as application engineer, manufacturing assembly, programmer, quality control, software developer, support specialists and trainers.[35] Such professionals usually work in a collaborative environment and are responsible for operating robots as well as researching, designing, creating, testing and troubleshooting problems.

The jobs that are emerging and opening up with the development of 3D printing are in the areas of 3D design, 3D computer-aided design (CAD) modeling, research and development (R&D), biological and scientific modeling, architecture/construction modeling, education, law and legal professions, new business opportunities, 3D-Printing-as-a-Service franchises and operations and administrative positions. [36] Jobs for designers who can translate a product idea into 3D printed objects will be opening up in 3D printing firms, as part of 3D design teams in companies and as freelancers. Such job seekers will be most competitive if they acquire hands-on experience with the latest 3D printing technologies and stay up to date with how 3D printing is used in companies and work processes. Job seekers skilled in 3D CAD modeling will support the work of 3D designers, both for mass 3D printing and for custom-designed 3D prototyping and manufacturing.

They will also need to posses modeling skills and be familiar with the constraints of specific materials, technologies and constraints. Research and development professionals who understand the intersections, possibilities and constraints between technology and consumer products will also be in demand, for example in fashion, jewelry, and other consumer product areas that will have to keep an eye on lowest costs and efficient production. 3D printing of products in other areas, such as medicine (e.g. prosthetics, replacement parts, tissue printing) will require people with a background in biomedicine and science. Such expertise will be needed in other high-precision industries such as aerospace, military and drone design and construction. 3D printing is also expected to have a disruptive impact in industries such as architecture, construction and engineering, where it could replace 2D construction blueprints with 3D models.

Thus skills and knowledge at the intersection of 3D printing and these areas will also be in future demand. In terms of education, jobs for educators who can teach such skills, both regarding 3D printing itself and interdisciplinary connection and intersections with other fields and subject areas, will become another emerging job opportunity. Such teachers will be needed in the Arts as well as the Sciences, and stay current with the latest trends and technologies that the various industries and fields will adopt. Many legal questions related to intellectual property rights of 3D printed designs and products will emerge with the possibility of copying, modifying and selling 3D designs that infringe on existing patents, copyrights and brands.

A whole new subfield of intellectual property rights issues for 3D printing is thus emerging for legal professionals. Regarding companies, 3D printing is not just creating new opportunities for design and production, but also for entrepreneurship and new business models. As the price of even the more

[34] Just as an example, the Linkedin job search list some 180 job openings for robotics engineers. https://www.linkedin.com/jobs/search/?keywords=robotics%20engineer&location=worldwide&locationId=OTHERS.worldwide&locationType=Y

[35] https://www.motoman.com/blog/index.php/want-to-get-a-job-in-robotics/

[36] http://www.businessnewsdaily.com/5125-3d-printing-jobs.html

advanced 3D printers begins to drop, individuals and companies that offer innovative design, process solutions and 3D printing on-site or through remote 3D printing will increasingly be able to utilize innovative opportunities in the emerging 3D printing ecosystem. Vendors that would like to utilize 3D-Printing-as-a-Service franchises could provide 3D printing services to local businesses, entrepreneurs or individuals in retail stores. Regarding operations and administrative jobs in 3D printing, as new businesses based around 3D printing spring up, they will require other, more common jobs, such as salespersons, administrators, etc. Speaking generally, a 3D printing technician is an emerging profession or career, something that did not exist before, thus any efforts to motivate existing employees and prospective students would help move a greater number of future professionals towards studying and engaging with this emerging field.

Regarding the skills that will be needed by workers in new age technology fields, there are three basic skill fields[37]. First, there are **cognitive skills**, which include digital literacy, as well as advanced problem-solving and creative and critical thinking skills. Second, there are **social and behavioral skills** like conscientiousness, grit, and openness to experience. Third, there are job- or occupation-specific **technical skills**, in this case related to robotics systems and 3D printing.

In this regard, the World Economic Forum lists three areas that will require systematic changes in education and training due to advances brought about by the Fourth Industrial Revolution.[38] The first challenge is **to connect education and employment**, which means that employers need to collaborate with schools and universities on the development of curricula and a shared practical knowledge of the market. The education system also needs to adopt a stronger focus on lifelong learning. The second challenge is to **improving forecasts regarding industry and the labor market**, so that governments, businesses and individuals are able to react quickly and appropriately. The third challenge is **disrupting education and labor policy**, related to improving the quality and relevance of learning, government policies that would ensure the required skills are taught to the national workforce.

While the ROTENA survey report provides an overview of the general educational and training challenges related to equipping the future workforce with relevant and needed skills to participate in the new age technology revolution, the key focus of the project for the report is on providing an overview of the entry-level, easily accessible courses that could motivate and excite prospective trainees, especially young people and students to pursue careers or further education in robotics and 3D printing. The next section thus presents the results of mapping existing training programs both in Europe and globally, and highlights some of the best practices (features) of such programs that will also serve as the background for the development of the ROTENA course and modules on the topic.

Conclusion

A global survey of 100 largest employers showed that they expect a total of 7.1 million jobs to be lost due to automation from 2015 to 2020. [39] Of these, two thirds will be lost in routine office and administrative tasks.

[37] https://www.brookings.edu/blog/future-development/2016/03/01/preparing-for-the-robots-which-skills-for-21st-century-jobs/

[38] https://www.weforum.org/agenda/2016/01/what-is-the-future-of-work/

[39] WEF 2016

On the upside, they expect a total of 2 million new jobs to be generated, predominantly in the areas of computers, mathematics, architecture and engineering.

Whether robotics and other technologies will in the end create more or less jobs than they make obsolete remains an open question, but it is clear that workers whose jobs are taken over by technology or transformed, will need to learn new skills and knowledge and also become familiar and adept at working together with robots. The same holds true for first-time employment seekers and young people who are still deciding on a career path.

5. OVERVIEW OF STANDALONE OPEN COURSES ON INTRODUCTORY ROBOTICS AND 3D PRINTING

5.1 Introduction

Over the past decade, the development of online platforms that enable and support various forms of e-learning has led to a proliferation of different types of online courses, many provided by the most prestigious universities and acknowledged experts. As the demands of the labor market and the skills and expertise needed by SME employers shift towards what we might label as new age, second machine age or industrial revolution 4.0 technologies (e.g. robotics and 3D printing), and while traditional vocational and higher education institutions are still slow to offer training and education in such topics, online courses might be able to fill this gap. Many analysts and experts contend that numerous new and emerging jobs will require knowledge and skills in building, programming and operating robots, robotic systems and 3D printing devices. The current shortcoming of the educational system lies mainly in failing to provide students with a first introduction to robotics and 3D printing, and thus getting them interested and motivated to further pursue careers in such topics. Since the demands of modern industry can shift quite rapidly, online courses can provide a rapidly adaptable tool that can reach a wide and diverse audience of interested learners, who can pursue specific knowledge and skills that will benefit them in the job market, for example though MOOCs (Massive Open Online Courses), which usually issue certificates of accomplishments, often for a fee.[40] If such courses are open to anyone with an internet connection, free of charge and available in English, they can potentially reach a wide international audience of learners, especially in countries where there are no such courses at educational institutions and for groups that are unable to (re)enter formal education.

One of the goals of the ROTENA project is to provide a general overview of the examples and best practices of online courses focusing on introductory robotics and 3D printing. Thus we have conducted a web-based search for such MOOCs and courses that are provided online, open to anyone and focused on teaching the basics of the two themes. While it is a bit tricky to determine what such introductory courses should entail, a preliminary overview of topics shows there should be a basic overview of the field, the skills and elements required, followed by the basics of how to build and program a robotic part, robot or robotic system, or in the second case, a 3D printer, and of how to operate the system for specific tasks. Sometimes an introduction also encompasses a general overview of the ethical, legal and societal implications of the topic. Introductory and basic courses in robotics should provide both motivation and the starting or additional knowledge for work and careers especially in computer science, software engineering, electrical engineering, mechanical engineering and mechatronic engineering.

Although there is much discussion about the large impact that robotics and 3D printing will have on the economies, job markets and workforces of European and other countries,[41] there are only few

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[40] Metha, Deepak. 2017. *The Future Of Massively Open Online Courses (MOOCs)*. Forbes. https://www.forbes.com/sites/quora/2017/03/23/the-future-of-massively-open-online-courses-moocs/#1de33f9b6b83

[41] Viola, Roberto. 2017. *The future of robotics and artificial intelligence in Europe*. https://ec.europa.eu/digital-single-market/en/blog/future-robotics-and-artificial-intelligence-europe
Guo, Jeff. 2017. *We're so unprepared for the robot apocalypse*. The Washington Post. https://www.washingtonpost.com/news/wonk/wp/2017/03/30/were-so-unprepared-for-the-robot-apocalypse/?utm_term=.93efb96dd225

open online courses available. We have focused our search using the key words introduction/introductory/basic, robot/robotics and 3D printing/additive manufacturing both on google and on the main MOOC platform providers (Coursera, Udacity, edX, FutureLearn etc.). Our search has shown that there are only a handful of such open standalone courses available, provided mainly by Anglo-Saxon Universities as MOOCs on MOOC platforms, along with a few provided by companies that produce robotics and 3D printing systems. While some vocational and higher education institutions do offer some basic teaching on robotics and 3D printing as part of their courses and studies,[42] these are not stand-alone and are usually not available as free, open courses. Some do, however provide free access to the lecture notes, videos and other material.[43] In this sense, it is important to distinguish between regular higher education lectures from which the material is now openly and freely available, and between MOOCs that also offer the supporting pedagogical framework, including quizzes, assignments, forums and interaction with teachers, assistants and a student body in a given course-duration timeframe.

5.2. Overview of open courses on introductory robotics

5.2.1 Open introductory robotics courses in Europe

Some vocational and higher education institutions in European countries do provide modules, courses, segments or elements on skills and knowledge in the field of robotics as part of their degree courses, usually within a Master's program. But with the exception of some UK universities (described below) that do provide introductory MOOCs, such courses are not standalone or open, only offer access to course materials or are dedicated to more advanced robotics topics, artificial intelligence or automation skills. As the general overview of European courses was limited given language barriers, we have specifically investigated the availability of introductory and basic courses on robotics and 3D printing in the ROTENA project partner countries. Similarly as with the general overview of Europe, with the UK exceptions, the courses or segments in partner countries are provided as part of vocational education, training or higher education degrees. Most are oriented towards industry, and the overall emphasis is on industrial robotics development, maintenance and automation.

Below are a couple of the more prominent examples of training and programs offered by vocational institutions and universities. In the **UK**, several universities offer Master's programs connected with robotics, automation and AI. For example, the Faculty of Engineering at the University of Bristol provides a 1-year Master's program in robotics that teaches a wide range of advanced engineering and computer science concepts.[44] In **Austria**, the FH Technikum Wien (University of Applied Sciences)

Wood, Lamont and Vinod Baja. 2016. *Service robots: the next big productivity platform*. http://usblogs.pwc.com/emerging-technology/service-robots-the-next-big-productivity-platform/
Michaels, Guy and Georg Graetz. Estimating the impact of robots on productivity and employment. VOX. CEPR's policy portal. http://voxeu.org/article/robots-productivity-and-jobs
Kaivo-oja, Jari. 2015. *The future of work: robotics*. European Agency for Safety and Health at Work. https://osha.europa.eu/en/tools-and-publications/publications/future-work-robotics/view

[42] MOOCs: Top 10 Sites for Free Education With Elite Universities http://www.bdpa-detroit.org/portal/index.php/comittees/high-school-computer-competition-hscc/29-education/57-moocs-top-10-sites-for-free-education-with-elite-universities.html

[43] For example, MIT: Introduction to Robotics https://ocw.mit.edu/courses/mechanical-engineering/2-12-introduction-to-robotics-fall-2005/; and Stanford University: Introduction to Robotics https://see.stanford.edu/Course/CS223A;

[44] The program focuses on robotics fundamentals, robotics systems, intelligent adaptive systems, image processing and computer vision and the technology and context of robotics and autonomous systems. It also provides the opportunity to carry out the final dissertation at the Bristol Robotics Laboratory - the UK's largest and most comprehensive robotics facility and a world-leading centre of robotics research. http://www.bristol.ac.uk/engineering/interdisciplinary/robotics/

offers a 6-semester mechatronics bachelor's degree program with an emphasis on robotics.[45] Another interesting initiative is provided by the Practical Robotics Institute Austria, which offers workshops and summer courses where participants can build and program various robots, while learning about sensors, actuators and programming languages.[46] In **Portugal**, the ATEC - Training Academy offers vocational training of young people and adults as well as further training for companies, in order to provide staff training and qualifications that are intended to meet the needs of industry in terms of staff training and qualification, including a 12-month specialization course in automation, robotics and industrial control.[47] In **Slovenia**, the Faculty of Electrical Engineering at the University of Ljubljana provides a study orientation (subjects) in robotics as part of the Bachelor's and Master's study program in Electrical Engineering. [48] In **Sweden**, University West for example offers a 2-year Master's program in Robotics and Automation, which provides the knowledge necessary to design and use robots.[49]

Focusing on standalone, open, online and free introductory robotics courses, most European providers of such MOOCs are UK universities on the FutureLearn platform and Swiss Universities on edX. While there are some additional MOOCs on robotics and various intelligent systems, they are at an advanced level or more specialized, and below we have focused only on the ones providing basic and introductory knowledge. Below are short descriptions of these MOOCs indicating providers, the content and outcomes that the learner can expect to learn in the course, along with a description of potential prerequisite knowledge necessary for the course.

University of Sheffield: Building a Future with Robots (FutureLearn)
by Sandor Veres
https://www.futurelearn.com/courses/robotic-future

Content
A 3-week (3h/w) free course on the (future) role of robots in society. In the near future, more of us will be working alongside robots, so knowledge of autonomous systems and robotics will be a helpful skill for a number of careers. The free online course will present some of the major challenges of working with autonomous systems, help you understand how researchers design robotic systems, how these connect to other fields of study, and the potential role of robotics in our everyday future. Behind-the-scenes access to research at Sheffield Robotics will demonstrate different robotic solutions for some of the world's most pressing needs, ranging from what factories of the future will look like, how we might use robots to help care for an aging population, how robots might be used in classrooms, how driverless cars will change the way we travel and much more.

Outcomes

[45] The program teaches the basic principles and knowledge in the areas of mechanics, electronics, computer science, sensor technology, processor technology, and actuator technology. Students learn how to program industrial robots and to operate and develop mobile robots. https://www.technikum-wien.at/en/study_programs/bachelor_s/mechatronics_robotics/
[46] The practical workshops provide an introduction to information science as well as mechanical and electronic engineering. Only in German: http://camps.pria.at/kurse/
[47] The course provides advanced knowledge of automatic production systems, based on the most recent technologies available in the industry. The main aim is to train technicians to design, install, maintain and repair of equipment in the areas of automation, robotics and industrial control. Only in Portuguese: https://www.atec.pt/cursos-formacao-profissional/tecnico-especialista-em-automacao-robotica-e-controlo-industrial.html
[48] The degree provides knowledge of kinematics, dynamics, robot control, robot vision and virtual environments, modern measurement and sensor systems, as well as systems for capturing and processing data. Only in Slovenian: http://spremenisvet.info/robotika/
[49] The program includes the basics of robot modeling and analysis, simulation techniques to mimic robots in a virtual environment, and programming robots, both virtual and physical. Practical work is conducted in a robotics and automation lab with modern robots of the type used in industry. https://www.hv.se/en/education/programme/master-in-robotics-and-automation-full-time-campus-tarau/

- analyzing and meeting the main challenges of working with autonomous systems;
- understanding some basic principles of robotic design;
- knowledge of robotics development and their potential effects;
- explaining existing and potential real-life robotic applications;
- understanding current and future developments in robotics, how and where they are being applied;
- thinking about our part in the robotics revolution;
- available Certificate of Achievement (for a fee).

Prerequisites

The course is open to anyone with an interest in robotics, and will be especially interesting to engineers, designers, technicians and enthusiasts who are keen to explore the role of robots in our economic and industrial future.

University of Reading: Begin Robotics (FutureLearn) (2017)

by Richard Mitchell, Timothy Threadgold and William Harwin

https://www.futurelearn.com/courses/begin-robotics

Content

The 4- week (3h/week) free online course explores the basics of robot design, and answers questions such as "What makes a robot?" and "Can anyone get a robot to do a particular task?" We will start with a history of real and fictional robots. Our experts will then help you explore the internals of a mobile robot using a combination of videos, animations, screencasts, articles, discussions and quizzes. You will discover the components of robot anatomy (the mechanics, electronics and computer "brain") and how they relate to one another and the sensors - the parts that enable the machine to perceive its surroundings. Then we will tackle the motors: how do you control your robot to help it avoid obstacles, head in the right direction and travel at an optimum speed? Finally, we will investigate the topic of robot behavior, and investigate questions such as "What can we learn about developing robots based on what we know about living systems?", "If we introduce a simple "brain", what influence does this have on the robot's behaviour?", "How is a robot's movement specified by what it perceives?" and "Can we create robots with basic instincts, and the ability to learn and co-operate with one another?". A weekly feature will enable you to meet the robots at Reading, from machines built by our students from scratch, to Baxter, an adaptive interactive industrial robot. You will also become acquainted to the basics of robot design through a series of simulations where you will test drive an Eric – our University of Reading mobile robot.

Outcomes

- learning a brief history of robots;
- learning about robot design (internal components);
- learning about robot behavior;
- getting acquainted with various robots, test driving a mobile robot.

Prerequisites

The course requires no prior knowledge or robotics material.

ETH Zurich: Autonomous Mobile Robotics (edX) (2017)
by Davide Scaramuzza, Marco Hutter, Margarita Chli, Martin Rufli, Roland Siegwart
https://www.mooc-list.com/course/amrx-autonomous-mobile-robots-edx

Content
A 15-week (5h/w) free introductory course on mobile robotics. Robots are rapidly evolving from factory workhorses, which are physically bound to their work-cells, to increasingly complex machines capable of performing challenging tasks in our daily environment. The objective of this course is to provide the basic concepts and algorithms required to develop mobile robots that act autonomously in complex environments. The main emphasis is put on mobile robot locomotion and kinematics, environment perception, probabilistic map based localization and mapping, and motion planning. The lectures and exercises of this course introduce several types of robots such as wheeled robots, legged robots and drones.

Outcomes
- learning the basic concepts and algorithms for robot locomotion, perception and intelligent navigation;
- applying these concepts for the design and implementation of autonomous mobile robots acting in complex environment;
- available verified certificate (for a fee).

Prerequisites
Good knowledge of basic mathematics, physics, system modeling, and control.

5.2.2 Open introductory robotics courses outside of Europe

The providers outside of Europe are more numerous and come mainly from the US and from Australia. While the major MOOC platforms provide several additional robotics and AI related courses, they are of either of a specialized or advanced nature. In this regard, Coursera for example offers Control of Mobile Robots (Georgia Institute of technology) and Aerial Robotics (University of Pennsylvania), while Udacity provides Artificial Intelligence for Robotics: programming a robotic car (Georgia tech). Udacity also provides a three month nanodegree learning program on the skills needed to become a robotics engineer. Given the objectives of ROTENA, we have not focused on these courses, but on the more basic introductory robotics MOOCs. These are provided by Coursera, Columbia University and the University of Pennsylvania on edX, the Queensland University of Technology on FutureLearn, and the Swinburne University of Technology on Open2Study. Below are short descriptions of these MOOCs indicating providers, the content and outcomes that the learner can expect to learn in the course, along with a description of potential prerequisite knowledge necessary for the course

COURSERA (University of Pennsylvania): Robotics Specialization (2017)
by Vijay Kumar, CJ Taylor, Daniel E. Koditschek, Daniel Lee, Jianbo Shi, Kostas Daniilidis, and Sid Deliwala
https://www.coursera.org/specializations/robotics

Content

The specialization consists of 6 courses (each 4-weeks, 2-5 h/week) that provide the building blocks of knowledge and skills for a specialization in Robotics.[50] Learners are introduced to the concepts of robot flight and movement, how robots perceive their environment, and how they adjust their movements to avoid obstacles, navigate difficult terrains and accomplish complex tasks such as construction and disaster recovery. You will be exposed to real world examples of how robots have been applied in disaster situations, how they have made advances in human health care and what their future capabilities will be.

Outcomes

You will learn both the theoretical background of robot flight and movement and how to program a robot to perform a variety of movements such as flying and grasping objects.

The Coursera course is free, but the certificate of accomplishment is only available for a fee.

Prerequisites

No background knowledge is required. The course will make use of free programming software (MATLAB).

COURSE 1 - Robotics: Aerial Robotics

Content

How can we create agile micro aerial vehicles that are able to operate autonomously in cluttered indoor and outdoor environments? You will gain an introduction to the mechanics of flight and the design of quadrotor flying robots and will be able to develop dynamic models, derive controllers, and synthesize planners for operating in three dimensional environments. You will be exposed to the challenges of using noisy sensors for localization and maneuvering in complex, three-dimensional environments. Finally, you will gain insights through seeing real world examples of the possible applications and challenges for the rapidly-growing drone industry.

Prerequisites:

- some familiarity linear algebra, single variable calculus, and differential equations
- some experience programming with MATLAB or Octave is recommended

COURSE 2 - Robotics: Computational Motion Planning

Robotic systems typically include three components: a mechanism which is capable of exerting forces and torques on the environment, a perception system for sensing the world and a decision and control system which modulates the robot's behavior to achieve the desired ends. In this course we will consider the problem of how a robot decides what to do to achieve its goals. This problem is often referred to as Motion Planning and it has been formulated in various ways to model different situations. You will learn some of the most common approaches to addressing this problem including

[50] The courses that make up the robotics specialization consist of several standalone courses with different target areas. Since the purpose of ROTENA is to focus on basic and introductory courses and elements, course 1 - Aerial Robotics might not be considered as one of these, as it focuses on flying robots.

graph-based methods, randomized planners and artificial potential fields. Throughout the course, we will discuss the aspects of the problem that make planning challenging.

COURSE 3 - Robotics: Mobility

How can robots use their motors and sensors to move around in an unstructured environment? You will understand how to design robot bodies and behaviors that recruit limbs and more general appendages to apply physical forces that confer reliable mobility in a complex and dynamic world. We develop an approach to composing simple dynamical abstractions that partially automate the generation of complicated sensorimotor programs. Specific topics that will be covered include: mobility in animals and robots, kinematics and dynamics of legged machines, and design of dynamical behavior via energy landscapes.

COURSE 4 - Robotics: Perception

How can robots perceive the world and their own movements so that they accomplish navigation and manipulation tasks? In this module, we will study how images and videos acquired by cameras mounted on robots are transformed into representations like features and optical flow. Such 2D representations allow us then to extract 3D information about where the camera is and in which direction the robot moves. You will come to understand how grasping objects is facilitated by the computation of 3D posing of objects and navigation can be accomplished by visual odometry and landmark-based localization.

COURSE 5 - Robotics: Estimation and Learning

How can robots determine their state and properties of the surrounding environment from noisy sensor measurements in time? In this module you will learn how to get robots to incorporate uncertainty into estimating and learning from a dynamic and changing world. Specific topics that will be covered include probabilistic generative models, Bayesian filtering for localization and mapping.

COURSE 6 - Robotics: Capstone project

The 6-week course will give you a chance to implement a solution for a real world problem based on the content you learnt from the courses in your robotics specialization. You will choose from two tracks - In the simulation track, you will use Matlab to simulate a mobile inverted pendulum or MIP. The material required for this capstone track is based on courses in mobility, aerial robotics, and estimation. In the hardware track you will need to purchase and assemble a rover kit, a raspberry pi, a pi camera, and IMU to allow your rover to navigate autonomously through your own environment. Hands-on programming experience will demonstrate that you have acquired the foundations of robot movement, planning, and perception, and that you are able to translate them to a variety of practical applications in real world problems.

Columbia University (NY): Robotics (edX) (2017)
by Matei Ciocarli
https://www.edx.org/course/robotics-columbiax-csmm-103x#!

Content
The 12 week (8-10 h/w) free course will teach you the core techniques for representing robots that perform physical tasks in the real world, focusing on the robot mind and body. We will learn about

two core robot classes: kinematic chains (robot arms) and mobile bases. For both robot types, we will introduce methods to reason about 3-dimensional space and relationships between coordinate frames. For robot arms, we will use these to model the task of delivering a payload to a specified location. For mobile robots, we will introduce concepts for autonomous navigation in the presence of obstacles.

Outcomes

- represent 2D and 3D spatial relationships, homogeneous coordinates;
- manipulate robot arms: kinematic chains, forward and inverse kinematics, differential kinematics;
- program and navigate mobile robots: robot and map representations, motion planning;
- plan complete robot systems;
- develop present and future applications for robots;
- available Verified certificate (for a fee).

Prerequisites

You should be familiar with college-level introductory linear algebra (vector spaces, linear systems, matrix decomposition), calculus (partial derivatives, function gradients), and posses basic knowledge of computer programming (variables, functions, control flow). Projects will be carried out in the Python language, with C++ as an option. Class projects will make use of ROS - the open-source Robot Operating System (www.ros.org) widely used in both research and industry.

University of Pennsylvania: Robotics - Fundamentals (edX) (2017)
by Camillo J. Taylor and Mark Yim
https://www.edx.org/course/robotics-fundamentals-pennx-robo1x

Content

The 12 week (8-10h/w) free course will enable you to learn the key mathematical concepts and tools used to design robots that excel in navigating a complex, unstructured world in environments such as aerospace, automotive, manufacturing and healthcare. You will learn how to apply concepts from linear algebra, geometry and group theory and the tools to configure and control the motion of manipulators and mobile robots. You will also learn how to use MATLAB, the standard robotics programming environment and learn step by step how to use this mathematical tool to write functions, calculate vectors and produce visualizations. You will get hands on experience applying your knowledge to projects using various simulations in MATLAB.

Outcomes

- describe, analyze and think critically about fundamental problems in robotics, such as how to change the position or configuration of a robot;
- learn the role of mathematics in describing robotic arms, mobile robots and other robotic platforms;
- learn to use the industry standard programming environment, MATLAB;
- available Verified Certificate (for a fee).

Prerequisites

You should be familiar with college-level algebra and trigonometry, the fundamentals of calculus and possess basic knowledge of computer programming (variables, functions, control flow, some knowledge of graphs).

Queensland University of Technology: Introduction to Robotics (FutureLearn) (2016)
by Peter Corke
https://moocs.qut.edu.au/learn/introduction-to-robotics-july-2016

Content
The aim of the 6-week course is to develop students' skills and knowledge of the fundamental mathematics and algorithms that underpin robotics, including representation of pose and motion, kinematics, dynamics and control.

Outcomes
- describe and explain what robots are and what they can do;
- describe mathematically the position and orientation of objects and how they move;
- describing the mathematical relationship between robot joint coordinates and robot tool pose;
- computing the rigid-body forces in a robot and design a robot joint control system (optional);
- applying the mathematical, algorithmic and control principles of robot arm manipulators to implement a working robot through physical construction and software development (optional project);
- reflecting on the future role and development of robots in human society;
- available Statement of attainment (free).

Prerequisites
Knowledge of basic programming (either of MATLAB or of an object-oriented programming language) and some of the following areas of mathematics: vectors and spaces, matrices, and eigenvalues and eigenvectors.

Queensland University of Technology: Introducing robotics: robotics and society (FutureLearn) (2017)
by Peter Corke
https://www.futurelearn.com/courses/robotics-and-society

Content
A 3-week (3h/w) free course exploring robotics applications, societal impacts and ethics of using robots. Robots are being applied in numerous areas, from mechanisation of industrial tasks to exploring places humans can't go. This course starts with your perceptions of robotics (books, movies, TV), describes different types of robots (defining a robot), and leads into a discussion of the future: knowing we can use robots, should we? We will use case studies to show how robotics is being applied to help solve key issues facing society today: food production, aging populations, transport, and environmental change.

Outcomes
- explaining what robots are and what they can do;
- discussing the ethical considerations of using robots to help solve societal challenges;
- reflecting on the future role and development of robotics in human society.

Prerequisites
This course is for anyone interested in discovering how our society currently uses robots and how we might use them to solve big challenges in the future

Queensland University of Technology: Introducing Robotics - Making Robots Move (FutureLearn) (2017)
by Peter Corke
https://www.futurelearn.com/courses/making-robots-move

Content
A 3-week (3h/w) free course focusing on understanding robot motion and joint control. Robot movement relies on the principles of kinematics – the motion of a body or bodies. The course will teach you to program forward kinematics equations in MATLAB and learn approaches to inverse kinematics. We will consider objects in a two-dimensional plane, exploring the concepts of position, pose, rotation, and translation. We will also look at examples of different types of robots and learn how to set their task and configuration. Then we will dive into control theory and learn to model dynamic systems including the electric motors and gearboxes that go into a robot. Your knowledge of the skills and tools used will be tested in practical MATLAB exercises.

Outcomes
- explain what robots are and what they can do;
- describe mathematically the position and orientation of objects and how they move;
- describe mathematically the relationship between robot joint coordinates and robot tool pose.

Prerequisites
The course requires mathematical knowledge and programming skills. You should be familiar with concepts from advanced high-school mathematics or engineering, in particular, analytic geometry and linear algebra (including points, vectors, matrices, matrix-vector and matrix-matrix multiplication, and linear transformations). You will also need to know how to program in MATLAB (online version available through FutureLearn).

Queensland University of Technology: Introducing Robotics - Build a Robot Arm (FutureLearn) (2017)
by Peter Corke
https://www.futurelearn.com/courses/build-a-robot-arm

Content
A 3-week (3h/w) free course that will tech you to design, build and program a simple robot, with at least two joints, that can draw a line through a number of points on a sheet of a paper. You'll design and construct the robot, write the software to control it, and then put it to the test. Design and build a robot arm: we will discuss the hardware and software choices you have for building your robot and some of the mechanical design choices you will have to consider. We will support you through your key design decisions and demonstrate motors, gears and mechanical construction. Move and test your robot arm: we will make the robot move in a coordinated way and draw straight lines on the worksheet. There are lots of ways you could actually build such a robot and that will depend on your skill level, your budget, or what equipment you can source. You might consider working in a group to share the expense of the development kit, or borrow the equipment you'll need. At the end of the course, you'll be invited to submit a video of your completed robot. A small number of participants will peer review your project and you'll review a small number of others.

Outcomes

- apply mathematical, algorithmic and control principles of robot arm manipulators;
- produce a working robot through physical construction and software development.

Prerequisites

You should understand mathematical, algorithmic and control principles of robot arm manipulators before starting. This includes concepts from advanced high-school mathematics or engineering, in particular, analytic geometry and linear algebra (including) points, vectors, matrices, matrix-vector and matrix-matrix multiplication and linear transformations.

Robotics kit: if you wish to build a robot arm, you will need access to robotic kits or components. If you are not able to buy or borrow equipment, you can still learn the build process through this course. How you build your robot depends on what resources you have access to. For this project, you might choose to purchase a LEGO Mindstorms NXT or EV3 development kit, something equivalent, or borrow hobby robot components. All of the task instructions, demonstrations, and worksheets will be provided. Software: You will need a 64-bit computer to install the MATLAB software and a custom software toolbox to control your robot. The software depends on the hardware you choose to use; for example, MINDSTORMS NXT toolbox (NXT kits) or the QUT EV3 MATLAB toolbox (EV3 kits).

Swinburne University of Technology: Mobile Robotics (Open2Learn) (2017)
by Michelle Dunn
https://www.open2study.com/courses/mobile-robotics

Content

This 4-week free online course will enable you to discover the world of mobile robots - how they move, how they interact with the world, and how to build them. We will learn of mobile in various environments, explore how they move, sense the world around them and how they make decisions. Finally we will combine this knowledge and apply what we've learned to build our own mobile robot.

Outcomes

- what is a robot, and specifically, a mobile robot
- why we need robots
- what subsystems make up robots
- types of robot movement and suitability for different environments
- how sensors work (proprioceptive v. exteroceptive; active v. passive)
- how feedback systems works
- create basic flow diagrams and pseudo code to program what a robot will do
- develop a list of design requirements for a robotic system
- design, implement and troubleshoot a robotic system
- available Statement of Accomplishment (free)

Prerequisites

The course requires no prior knowledge or robotics material.

6. OVERVIEW OF STANDALONE OPEN COURSES ON INTRODUCTORY 3D PRINTING

6.1. Overview of open courses on introductory 3D printing

While 3D printing has been the subject of large expectations regarding the impacts on (personal) manufacturing, design, economy and society in general, it is still a technology that has started to spread only recently as compared to robotics and automation. Although hobby and limited-range manufacturing 3D printers are now in the range of many consumers, more sophisticated and capable 3D printers still cost upwards of half a million dollars. In this regards, we can expect that prices will continue to decline as both more businesses and more consumers start to adopt 3D printing technologies, and the technology becomes more developed due to market demands. As 3D printing is not (yet) an established field of science and technology (such as robotics), we can expect that it will probably not be taught in the form of courses by most vocational and higher education institutions (with the exception of some classes on manufacturing technologies), but rather in the form of MOOCs and (fee-based) short introductory courses and workshops. Regarding the potential impact of 3D printing on businesses, Delloite University offered a 2016 online course "3D Opportunity: Additive Manufacturing for Business Leaders".[51]Perhaps a bit surprisingly, there are no courses on 3D printing on the edX and FutureLearn MOOC platforms, which is probably connected with a lack of university courses on the topic. On the other hand some of the major companies that sell and produce 3D printing technologies also offer materials and (free) training for 3D printing.[52]

6.1.1 Open introductory 3D printing courses in Europe

Similar as with the standalone open online courses on introductory robotics, there are very few providers of such courses on 3D printing within Europe. No European universities offer MOOC courses connected with 3D printing on any of the MOOC platforms. A general search provided a few elements of 3D printing in the scope of Master's programs, mostly as part of advanced manufacturing and materials engineering Master's programs, for example the UK University of Sheffield Additive manufacturing and advanced manufacturing technologies.[53] Another interesting example from the UK is the Master's program in Additive Manufacturing[54] at the Anglia Ruskin University, which is described as being the UK's only dedicated masters program with a focus on 3D printing government, funded by the government in order to increase the number of skilled graduates in this field[55].

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[51] https://www.class-central.com/mooc/2240/novoed-3d-opportunity-additive-manufacturing-for-business-leaders

[52] For example iMakr https://www.imakr.com/en/training-consulting-for-3d-printing/710-introduction-3d-printing-training.html; GoPrint3D https://www.goprint3d.co.uk/3d-printer-training/; RoboSavvy https://robosavvy.com/store/welcome-to-the-world-of-3d-printing-training-course.html; etc.

[53] The 1-year program provides knowledge and skills in additive manufacturing (also known as 3D printing) and advanced manufacturing technologies. The course has been developed to meet the demands of industry and expose new graduates and professional engineers to cutting-edge manufacturing techniques and applications.
http://www.sheffield.ac.uk/postgraduate/taught/courses/engineering/mechanical/additive-manufacturing-advanced-manufacturing-technologies-msc-res

[54] The 1-year program covers a range of topics from product design to 3D CAD modelling, from additive manufacturing strategy to engineering management, equipping students with the knowledge required to produce prototypes and products across a range of industries including the biomedical and aviation sectors. The program provides access to advanced computer based analysis and modelling software, together with leading-edge engineering facilities including 3D printers and a metal direct metal laser sintering machine.
http://www.anglia.ac.uk/study/postgraduate/additive-manufacturing

[55] http://www.anglia.ac.uk/news/government-funding-for-new-3d-printing-course

Some secondary schools organize clubs and workshops for 3D printing, which are mostly the result of individual teacher engagements with occasional collaboration of 3D print companies. Similar collaborations can be found between various types of maker/DIY communities and companies or research institutions.[56] Practically the only open free online course that we could locate is provided on the ALISON e-learning platform.[57] Short standalone courses are mostly offered as workshops and summer schools, or as part of more extensive CAD courses, but in contrast to at least some courses on robotics, these are offered for a fee and usually require the presence at a physical location where hands-on work with 3D printers is available.

We have also investigated the availability of such courses in the ROTENA partner countries. Below are a couple of examples of available training courses. In the **UK**, the London Metropolitan University offers a 10-week (2 h/week) course on 3D printing and rapid prototyping.[58] In **Portugal**, the GetReady4 3D company provides an online course on 3D Printing.[59] In **Slovenia**, the RogLab makerspace provides fee-based training and open access to 3D printing equipment.[60]

ALISON: Learn how to use a 3D printer (2017)
https://alison.com/course/how-to-use-a-3D-printer

Content
The free 2-3 hour online course introduces the hardware and software technology behind 3D printing. You will learn about the different plastic filaments that are used and you will pick up tips on how to feed the plastic filament into the 3D printer for optimal performance. You will learn about the different components of a 3D printer such as the extruder nozzle and contact sensor and their functions. You will then learn how to set up and calibrate a 3D printer so that the object is printed correctly on the printer base plate. You will learn about different 3D print software that can be used to design 3D objects and the importance of using 3D model repair to eliminate errors in the design that can cause defects in the printed object.

Outcomes
- describe how to set up and use the Printrbot Simple 3D printer;
- describe the features of 3D Builder software and how it can be used for 3D printing;
- explain the importance of 3D model repair;
- describe the types of 3D objects that can be printed;
- available certificate of accomplishment (Alison Diploma) (for a fee).

Prerequisites

[56] For example in Slovenia
[57] An e-learning provider and academy founded in Galway, Ireland in 2007. Its main objective is to enable people to gain basic education and workplace skill, and a majority of its learners are located in the developing world.
[58] The course provides knowledge of the different 3D printing systems on the market and their specific design requirements for production. It covers an introduction to 3D printing technologies, software used to create models for 3D printing, how to create valid models for 3D printing and export options, 3D file fixing, verification and software, live hinges and other "click fits" and producing your own 3D model choosing from one of three technologies (EnvisionTEC Perfactory, Z-corp, SLS). http://www.londonmet.ac.uk/courses/short/3d-printing-rapid-prototyping/
[59] The course provides highlights of the technology, the 3D printing process, its macro flow and ecosystem, a step-by-step guide to transform your ideas into reality and business opportunities with 3D. http://www.sabe-online.com/products/3d-printing
[60] The 3D workshops are based on the model of a Fabrication Laboratory (Fab Lab) and provide the basic technology, services and education for rapid prototyping. They are aimed at a wide spectrum of users – from students and professionals in the fields of design, architecture and visual arts to passionate makers and curious children. http://www.roglab.si/en/3d-workshop

The course should be of interest to professionals in the areas of engineering, design and manufacturing who would like to learn more about 3D printing and its applications, as well as to all earners who would like to learn more about 3D printing and its future applications.

Computer Training Wales company: 3D printing course.
http://www.computertrainingwales.co.uk/courses/computer-aided-design/3d-printing-training.html

Content

This 1-day intensive fee-based course teaches how to design, optimise and manufacture physical components using the 3D printing process. You will work first with design projects before moving on to generating a number of 3D components. This course is offered one to one, in which you will first design a number of component before learning how to fabricate these designs using the 3D Printer. 3D Printing is a completely new group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional Computer Aided Design data.

Outcomes

- printer set up;
- leveling the build platform;
- loading & changing filament;
- print a sample model;
- download an open source model;
- slice the model in Makerware;
- design a basic part in 3D CAD;
- prepare your model for print;
- convert the model to STL/OBJ format;
- verify if your model is manifold;
- 3D Printing software;
- open and position your model;
- speed vs resolution;
- automatic support structures;
- maintaining your 3D printer;
- identify & solve common print issues;
- replace the cover tape on your platform;
- re-leveling the build plate;
- replacing the print nozzle.

Prerequisites

The course is intended for inventors, entrepreneurs, makers, designers, architects, artists and creative people who would like to gain hands on experience of 3D printing, and for those thinking of getting a 3D Printer.

GetReady4 3D company. 3D Printing
by Diogo Quental and Nadia Yaakoubi
http://www.sabe-online.com/products/3d-printing

Content

The fee-based 120-minute course enables you to learn everything about the 3D printing process, understand its benefits, and demystify some preconceived ideas. You will also identify the major players within the 3D printing ecosystem and understand that there’s a place for new business models waiting for you. With easy to follow segments and plenty of real world examples, you will learn how to take advantage of this amazing technology.

Outcomes

- understand the fundamentals of 3D printing;
- know the 3D printing process and ecosystem;
- understand the steps of the printing process;
- materialise your idea into a real 3D object;
- distinguish among printers, materials, and techniques;
- understand the business potential of 3D printing technology.

Prerequisites

The course is intended for anyone with an interest in 3D printing, anyone who wants to take advantage of the 3D printing business opportunities, professionals and business leaders who want to understand this new industrial revolution as well as the potential impact on their area of activity, and students.

6.1.2 Open introductory 3D printing courses outside of Europe

Similar as with introductory robotics courses, there are at least some 3D printing open online courses by providers outside of Europe, mainly from the US. The best example is probably the 5-part COURSERA course that provides the basics for a 3D printing specialization. A few other courses are available from UDEMY and from the 3D printer company Stratasys.

COURSERA (University of Illinois - Illinois Makerlab, Autocad, Ultimaker): 3D Printing Specialization (2017)
by Vishal Sachdev, Jeffrey Smith, Matthew Griffin, Jeffrey A. Ginger and Aric Rindfleisch
https://www.coursera.org/specializations/3d-printing

Content

This MOOC specialization is composed of 4 courses (each a 2-week, 3-4 h/week course) that provide a rich understanding of what 3D printing is, how 3D printers work, and how this new technology is being used by both individuals and firms to revolutionize our world. In addition, you will acquire a set of skills that will enable you to create digital designs that you can transform into physical objects. These skills can be used to help you launch a career in the growing field of 3D printing, be the 3D printing expert in your current firm, or just make the things you need.

Outcomes

You will be able to create physical objects using 3D printing design programs, scanners, and printers. The Coursera course is free, but the certificate of accomplishment is only available for a fee.

Prerequisites

No background knowledge is required. The course will make use of 3D printing software.

COURSE 1 - The 3D Printing Revolution

Content

The course will demonstrate how 3D printers work, show what people make with them, and examine the 3D printing ecosystem. It will also explore the future of 3D printing and discuss how this technology will revolutionize our world. The course materials include informative video lectures, on-location interviews with a variety of 3D printing experts, and engaging hands-on exercises.

Outcomes

Learners who complete this introductory course will have a solid understanding of 3D printing and its revolutionary potential, and will be able to print and customize 3D designs.

COURSE 2 - 3D Printing Applications

Content

This course will help you understand how 3D printing is being applied across a number of domains, including design, manufacturing, and retailing. It will also demonstrate the special capabilities of 3D printing such as customization, self-assembly, and the ability to print complex objects. In addition to business applications, this course will also examine how individuals, including those in developing countries, are using this technology to create solutions to the problems they face. This course will also provide an overview of design thinking and how you can use this framework to develop ideas that can be turned into objects.

Outcomes

Learners who complete this course will obtain a rich understanding of the capabilities of 3D printing and how to think about designing objects for this new technology.

COURSE 3 - 3D Printing Software

Content

This course will demonstrate how to use 3D printing software to create digital designs that can be turned into physical objects. It will also demonstrate how 3D scanners work to turn physical objects into digital designs. This course is hands-on in nature and will provide step-by-step instructions to guide you through two popular 3D modeling programs, Tinkercad and Fusion 360.

Outcomes

Learners who complete this course will be able to use 3D software to design a wide variety of objects for both personal and professional use. In addition, learners who enroll in the course certificate will receive extended free access to Fusion 360 (provided by Autodesk).

COURSE 4 - 3D Printing Hardware

Content

This course will provide an in-depth exploration of desktop 3D printing hardware. It will examine the history of desktop 3D printing and demonstrate how 3D printers are made and how they work. This course will also provide step-by-step instructions for how to use and repair a 3D printer. It will also explore the different types of materials that can be 3D printed and will demonstrate how you can create various objects using these tools and materials.

Outcomes
Learners who complete this course will be able to successfully operate, repair, and upgrade a 3D printer. In addition, learners who enroll in the course certificate will be able to purchase a desktop 3D printer at a discounted price (provided by Ultimaker).

COURSE 5 - 3D Printing Capstone

Content
The capstone will integrate the learning acquired from the four courses in the 3D Printing Specialization through a hands-on project. Specifically, you will be guided through a step-by-step process in which you imagine, design, make, and share a 3D printed object.

Outcomes
This project will enable you to turn an idea into an object using the knowledge and skills acquired through the other courses. You will be able to obtain an actual 3D print of the object you design at a discounted price through our corporate partners, 3D Hubs and Shapeways.

UDEMY: How to Start 3D Printing at Home - Even Without a 3D Printer
by Jason King
https://www.udemy.com/introduction-to-3d-printing-at-home/

Content
The short fee-based course teaches what 3D printers are, how they work, how to purchase one and how to use it to create amazing 3D prints. It demonstrates how to design a simple chess piece using two free design tools, Tinkercad and OpenSCAD. After the course you will be able to start designing your own products. This is not an MOOC course, but an online course consisting of videos, slides and on screen demonstrations.

Outcomes
- learn the fundamentals of 3D printing including the history, methods, kinds of 3D printers, how to design your own models and share them around the world;
- create their own 3D models using CAD software;
- explore new business models that take advantage of 3D printing and the customizability aspect; and
- how to monetize your 3D Designs.

Prerequisites
This course is for complete 3D printing beginners who are curious about what's involved in buying and using a 3D printer for home use.

UDEMY: The Fundamentals Of 3D Printing
by Jeffrey Ito
https://www.udemy.com/fundamentals-of-3d-printing/

Content

The short fee-based course teaches the basic terms and definitions of 3D printing along with the history of the technology. One will be able to learn how to use a 3D printer and learn its potential future applications. There are also case studies on successful businesses already using 3D printing for customization. We take you through the creation of your own 3D model and walk you through 3 of the most popular 3D printing services to print, sell and share your design. This is not an MOOC course, but an online course consisting of videos, slides and on screen demonstrations.

Outcomes

- learn the fundamentals of 3D printing including the history, methods, kinds of 3D printers, how to design your own models and share them around the world;
- create their own 3D models using CAD software;
- explore new business models that take advantage of 3D printing and the customizability aspect; and
- how to monetize your 3D Designs.

Prerequisites

The course is suitable for makers, entrepreneurs, inventors, engineers, architects, artists and explorers.

STRATASYS[61]: 3D printing curriculum - introduction to 3D Printing (2017)
http://www.stratasys.com/industries/education/educators/curriculum/introduction-to-3d-printing

Content

This is not an online course, but a curriculum guide that was developed by Stratasys in order to teach individuals and provide trainers and educators with an introductory curriculum for teaching the basics of 3D printing. The course is intended to prepare students for current and emerging careers in making use of 3D printing, with a knowledge of the technology's advantages and limitations. The course is designed as a 14-week (4-6 h/week) course divided into lectures and lab practice. It provides a brief history and the basics of 3D printing and CAD, the workings and technologies used by 3D printers, practical work and a framework for a practical project assignment.

Outcomes

- produce a fully functional moving part in a single print;
- explain current and emerging 3D printing applications in the manufacturing field;
- understand the advantages and limitations of each 3D printing technology;
- evaluate scenarios and recommend the appropriate use of 3D printing technology;
- identify opportunities to apply 3D printing technology for time and cost savings.

[61] The company is a manufacturer of 3D printers and 3D production systems for office-based rapid prototyping and direct digital manufacturing solutions. http://www.stratasys.com/

Prerequisites

The curriculum guide is intended both for use by students and for educators to design introductory 3D printing courses.

7. ROTENA EUROPEAN SURVEY

In order to determine what the needs, expectations and the conditions among the actual providers, users, and the ROTENA project conducted an extensive web-based European survey,

The survey questionnaire was of a structured type, consisting of 20 questions, divided into two sets, one focusing on robotics (15 questions) and the other on 3D printing (5 questions). We focused on three key groups of stakeholders - on providers of vocational education and training, on SMEs as potential users of robotics and 3D printing and employers of individuals with the necessary skills, and the individuals who could be interested in pursuing such knowledge, skills and careers in the future. The questionnaire was developed in English and then translated into all partner languages (Portuguese, German, Swedish, Slovenian). All language versions were installed in the online web survey system 1KA, and data collection took place from February 2017 to April 2017. Invitations were sent out when the survey was opened as well as throughout the duration of the survey. Several channels were used, from partner networks to personal invitation and posts on social networks and websites.

When the survey was closed, we had received valid 150 replies. Of these, 28 (19%) were from representatives of an SME, 36 (24%) were from representative of a course/training provider institution, and 86 (57%) were from individuals.

Main Results

- 36% or respondents had no knowledge of automation and robotics in an industrial setting.
- 83% thought that the use of robots in a company can be beneficial.
- 38% or respondents were already using robotic devices in their company, 38%.
- 79% of respondents could identify tasks in their company that could be automated or carried out by a robot.
- 63% of respondents said that their company is considering using robotic devices in the future.
- 58% of SMEs indicated that their employees would benefit from more knowledge/training about the use of robotics.
- 96% of respondents thought schools and educational institutions should provide more robotics skills/knowledge training.
- 36% of respondents knew how to use a 3D printer. The answers show that there are needs for additional education and training opportunities in 3D printing that are easily accessible to SMEs.
- 45% of respondents already uses 3D printing in their company.
- 82% of SMEs thought that their employees would benefit from more knowledge/training about the use of 3D printing.
- 67% of SMEs thought that the use of 3D printing would improve their competitiveness and/or reduce costs.
- 86% of respondents thought that schools and educational institutions should provide more 3D printing skills/knowledge training.
- 90% of respondents thought that in the future, knowledge of robotics could give them a professional advantage in job seeking or their work.
- 83% of respondents would consider taking a course/module about robotics if it were available for free.
- 58% of respondents were interested in building and programming robots with 42% wanting introductory and basic knowledge of robotics.

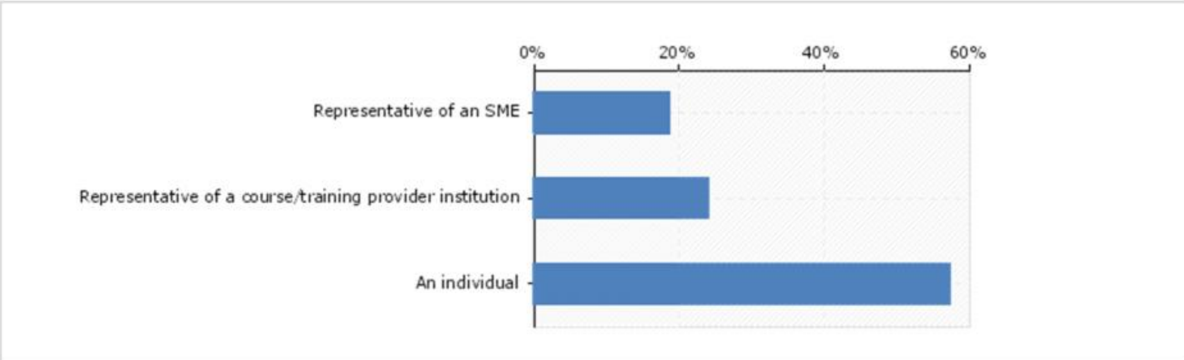
- 54% or respondents could envisage their work being carried out by a robot.
- 23% of the institutions responded said they offer any stand-alone robotics courses. There is a need for additional stand-alone courses on the topic of robotics that can be adapted by institutions to suit their own curricula and needs.
- 9% of the institutions responded said they offer any stand-alone 3D printing courses. However, 33% offered some kind of module.

Survey Conclusions

- Given that more than two thirds of the surveyed SMEs are considering to use robotics devices in the future, this further confirms a growing need for employees skilled in the production, maintenance and operation of such devices.
- This overall datum shows that the demand for robotics devices and robots will further increase in the future, and that the demand for employees who have knowledge and skills in handling such devices will equally increase.
- The two thirds of affirmative responses show that there is a need not only for new students and trainees in robotics, but also for online courses that would help existing employees gain additional knowledge and skills in the field.
- The majority in favor of more such training in schools and educational institutions also confirms the need for online courses and materials that can be used and adapted to suit specific curricula and training.
- As with robotics, the answers indicate that not only future workers, but also existing employees could have an interest in gaining additional training and skills.
- As with robotics, the majority in favor of more such training in schools and educational institutions also confirms the need for online courses and materials that can be used and adapted to suit specific curricula and training.

Detailed Reponses

Please select the type of survey most appropriate given your position: (n = 150)

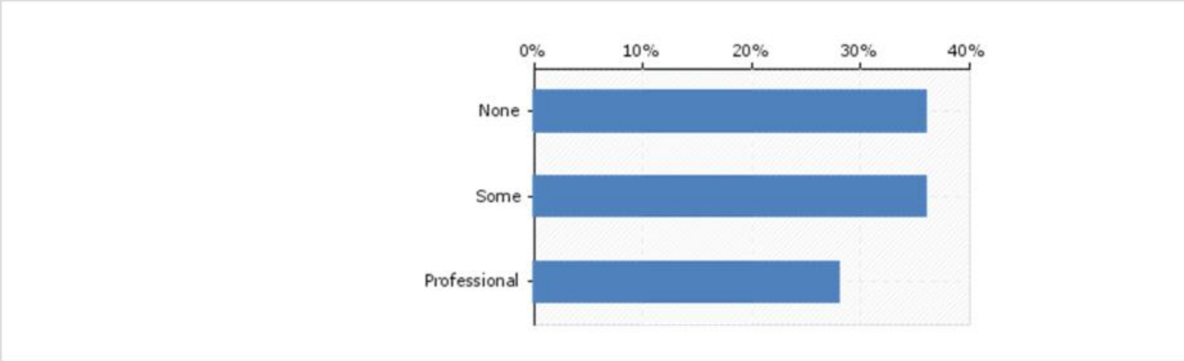


<u>**SME representatives on robotics**</u>

We first inquired about the use and value of robots in SMEs.

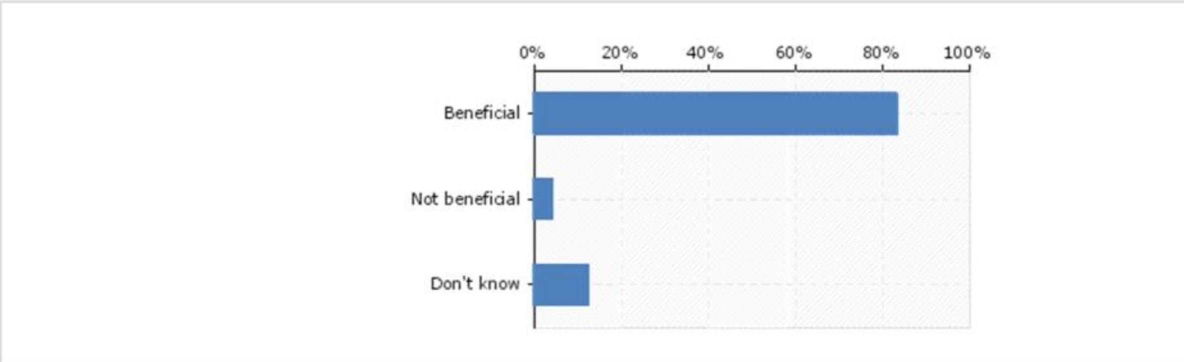
Regarding their knowledge of automation and robotics in an industrial setting, 36% (9) said that they had no such knowledge, 36% (9) had some knowledge and 28% (7) had professional knowledge. We can see from the table below that the answers were quite evenly distributed between no knowledge and some knowledge, with a slightly lower proportion of representatives with professional knowledge.

What is your knowledge of automation and robotics in an industrial setting? (n = 25)



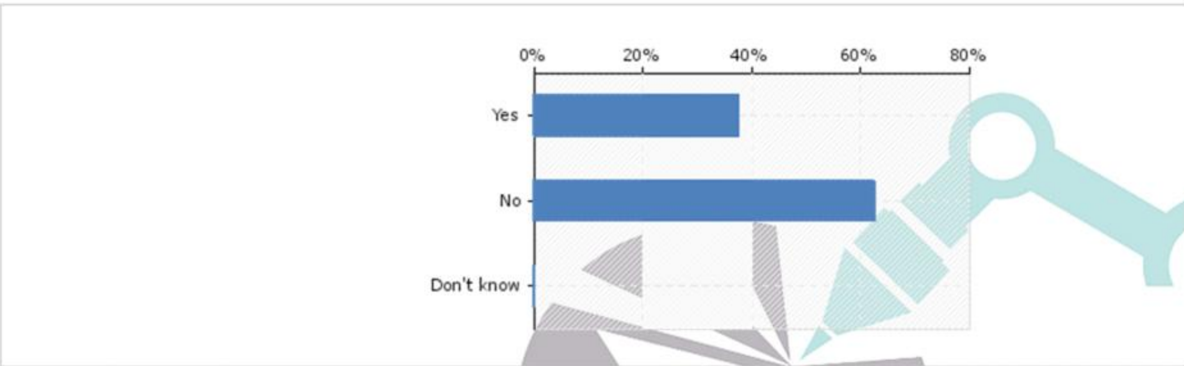
83% (20) thought that the use of robots in a company can be beneficial, 4% (1) that it is not beneficial, while 13% (3) did not know. The majority of responses judging the use of robots as favorable for an organization indicates both a need and an interest for robotics and automation among the surveyed SMEs.

Do you think the use of robots in an organization can be: (n = 24)



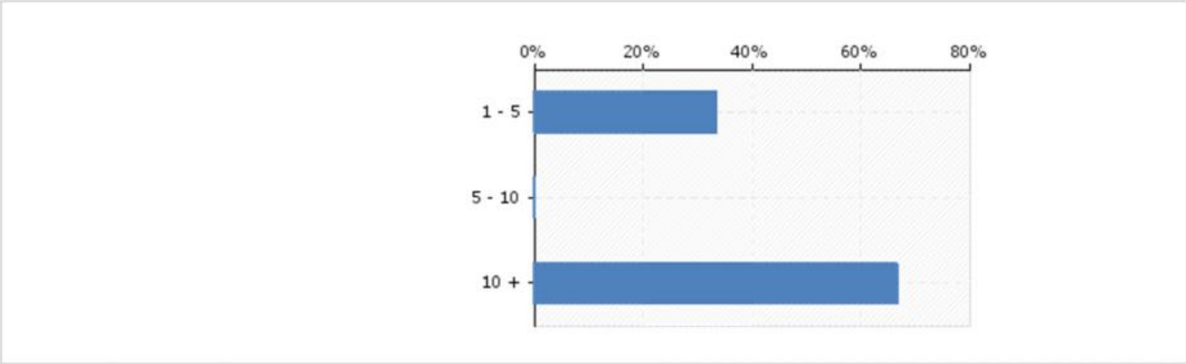
About the use of robotic devices in their company, 38% (9) were already using them, while 63% (15) did not. The responses show that robotics devices are already in use among a sizable number of the surveyed SMEs, but a majority are nevertheless not using any.

Does your company use robotic devices? (n = 24)



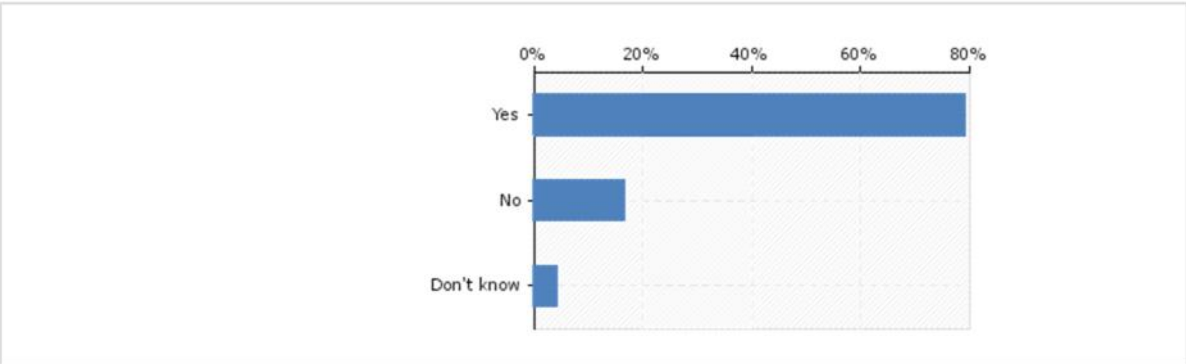
Of the robotics users, 33% (3) of the SMEs used 1-5 robotic devices, while 67% (6) used 10 or more.

How many? (n = 9)



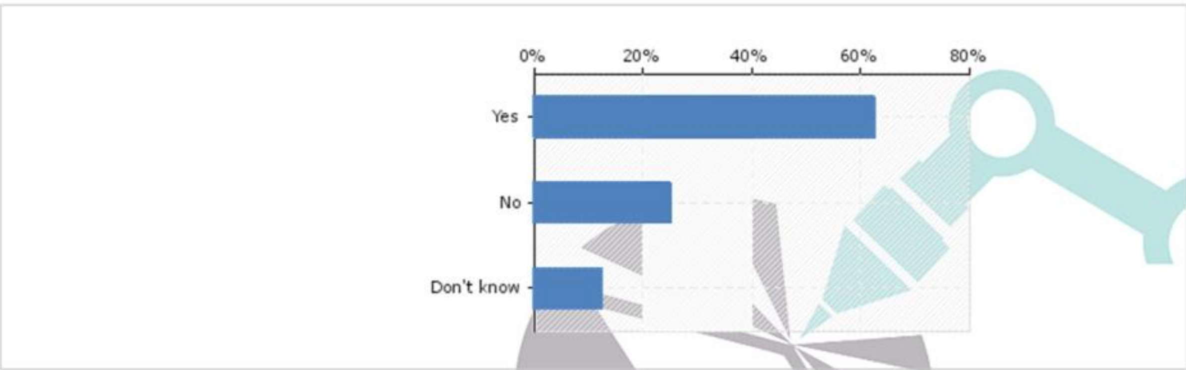
We also asked the SME representatives whether they could identify tasks in their company that could be automated or carried out by a robot, and 79% (19) could think of such tasks, while 17% (4) could not. 4% (1) did not know. This datum shows that the demand for robotics devices and robots will further increase in the future, and that the demand for employees who have knowledge and skills in handling such devices will equally increase.

Thinking about the whole of your company, can you identify tasks that could be automated or carried out by a robot? (n = 24)



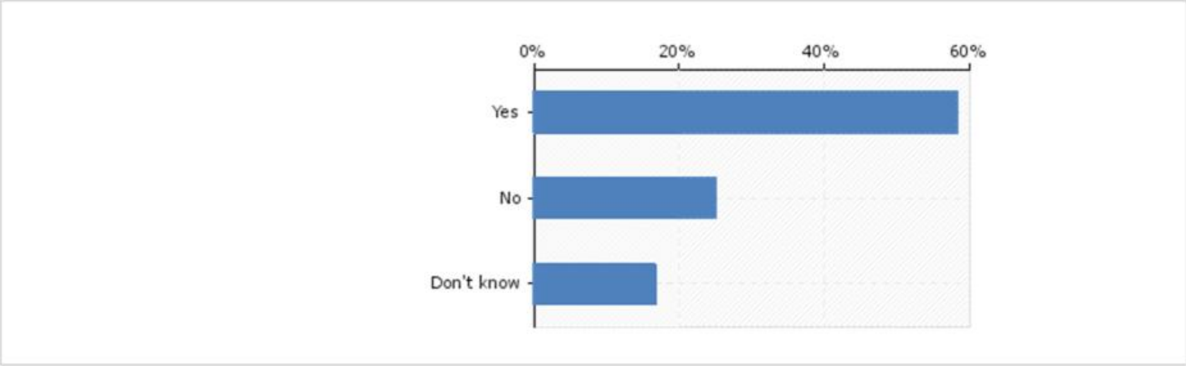
A majority of 63% (15) further said that their company is considering using robotic devices in the future, 25% (6) said they did not, and 13% (3) did not know. Given that more than two thirds of the surveyed SMEs are considering to use robotics devices in the future, this further confirms a growing need for employees skilled in the production, maintenance and operation of such devices.

Is your company considering using robotic devices in the future? (n = 24)



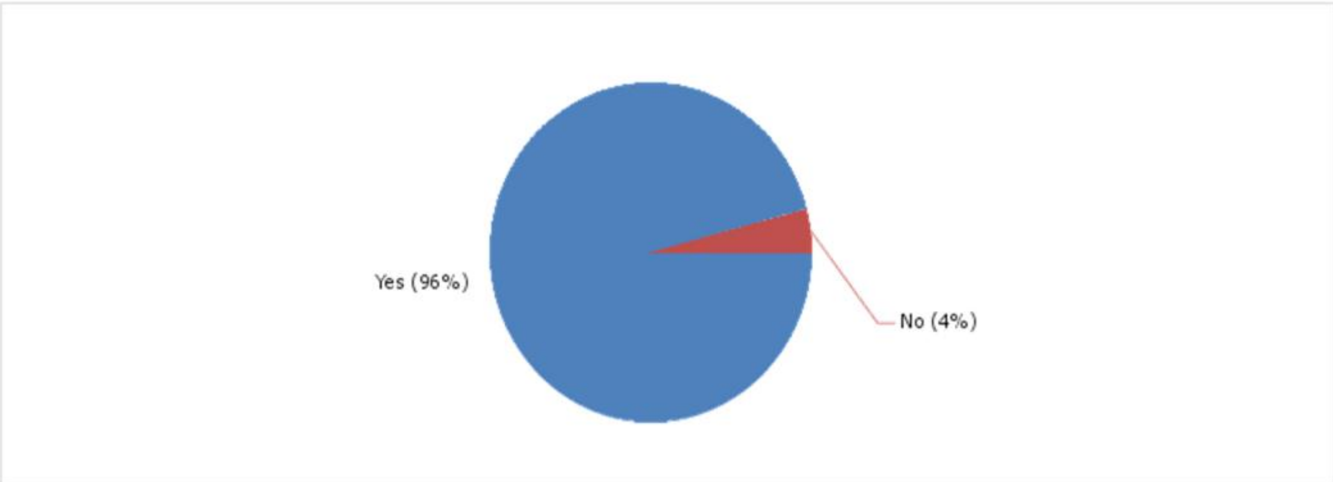
To the question whether their employees would benefit from more knowledge/training about the use of robotics in business, 58% (14) answered affirmatively, 25% (6) answered negatively and 17% (4) did not know. The two thirds of affirmative responses show that there is a need not only for new students and trainees in robotics, but also for online courses that would help existing employees gain additional knowledge and skills in the field.

Would your employees benefit from more knowledge/training about the use of robotics in business? (n = 24)



All of 96% (23) but one of the respondents thought schools and educational institutions should provide (more) robotics skills/knowledge training. The majority in favor of more such training in schools and educational institutions also confirms the need for online courses and materials that can be used and adapted to suit specific curricula and training.

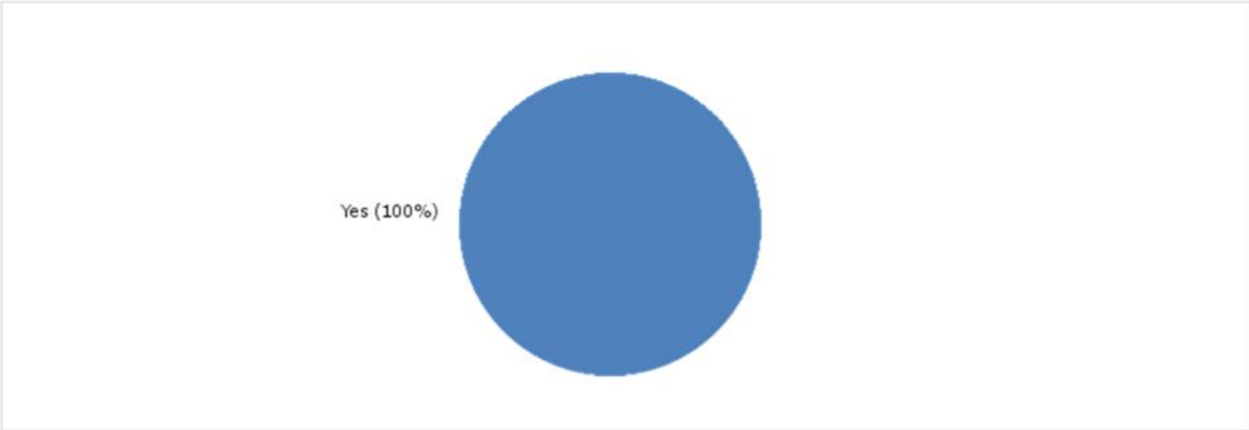
Do you think that schools and educational institutions should provide (more) robotics skills/knowledge training? (n = 24)



SME representatives on 3D printing

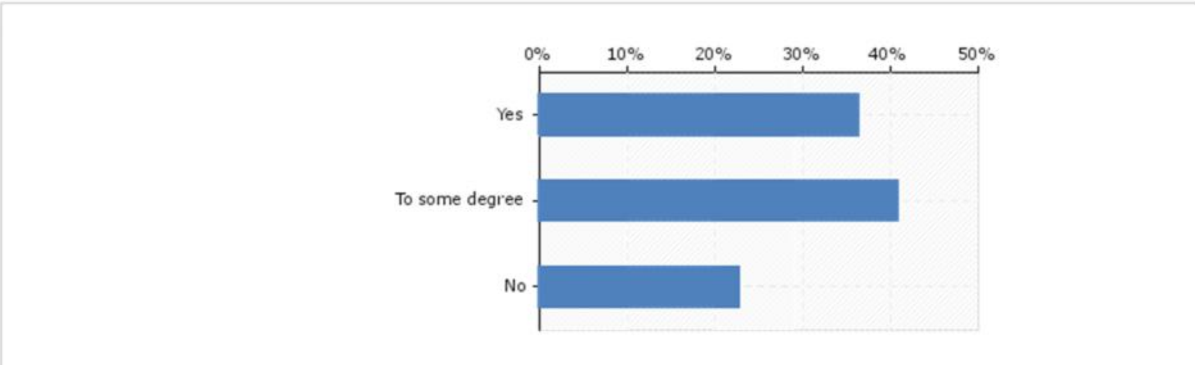
All respondents (22) said that they had already heard of 3D printing.

Have you heard of 3D printing? (n = 22)



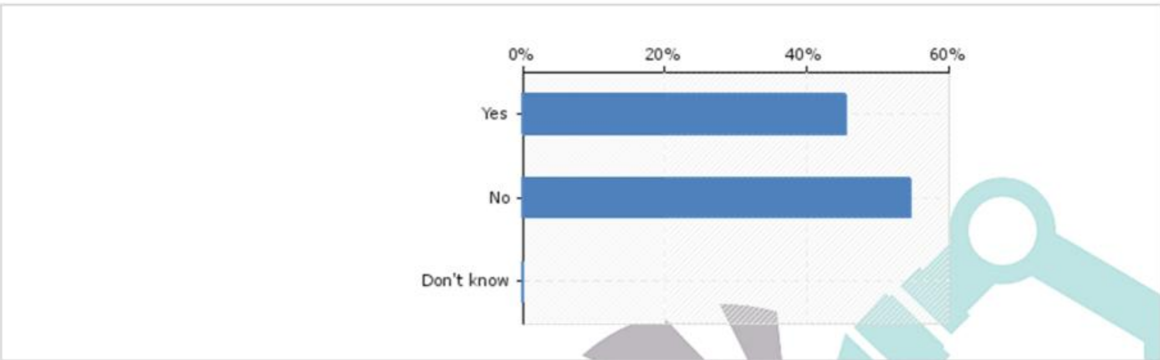
Of these, 36% (8) knew how to use a 3D printer, 41% (9) had some knowledge and 23% (5) had no knowledge. The answers show that there are needs for additional education and training opportunities in 3D printing that are easily accessible to SMEs.

Do you know how to use 3D printing? (n = 22)



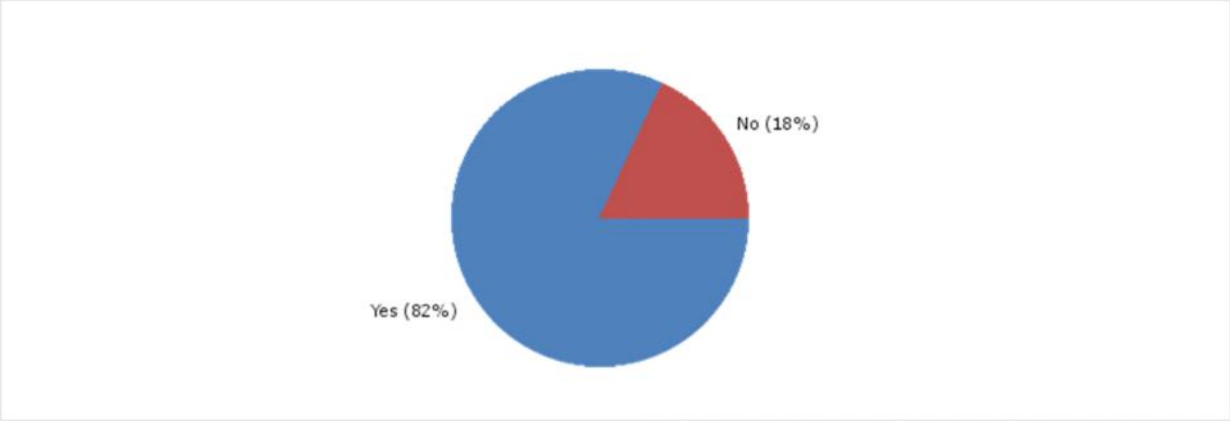
Regarding whether their company already uses 3D printing, 45% (10) answered in the affirmative and 55% (12) answered no. While almost half of the surveyed SMEs already use 3D printing, the other half shows there are still many potential companies that could be future users.

Does your company already use 3D printing? (n = 22)



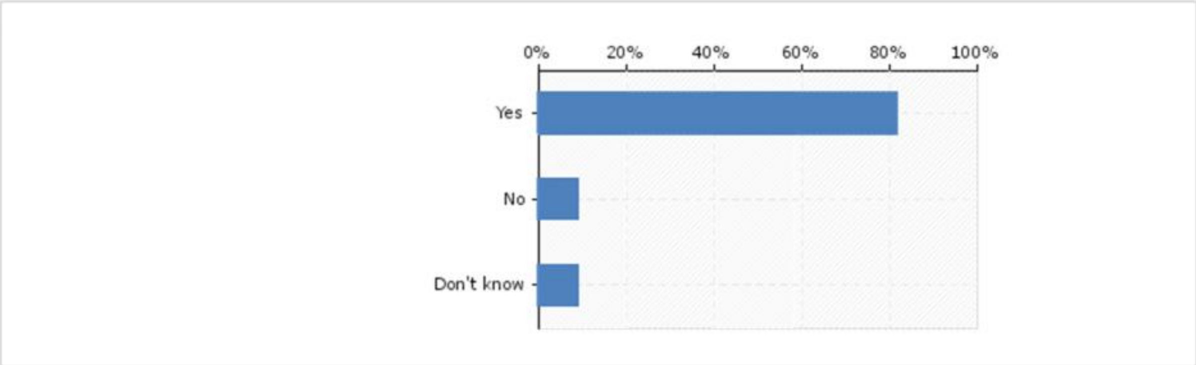
Most, 82% (18) would like to know more about the beneficial uses of 3D printing in industry, while 18% (4) would not. As with robotics, the majority interest in more knowledge of 3D printing uses shows the need and opportunity for additional courses and training in 3D printing.

Would you like to know more about the beneficial uses of 3D printing in industry? (n = 22)



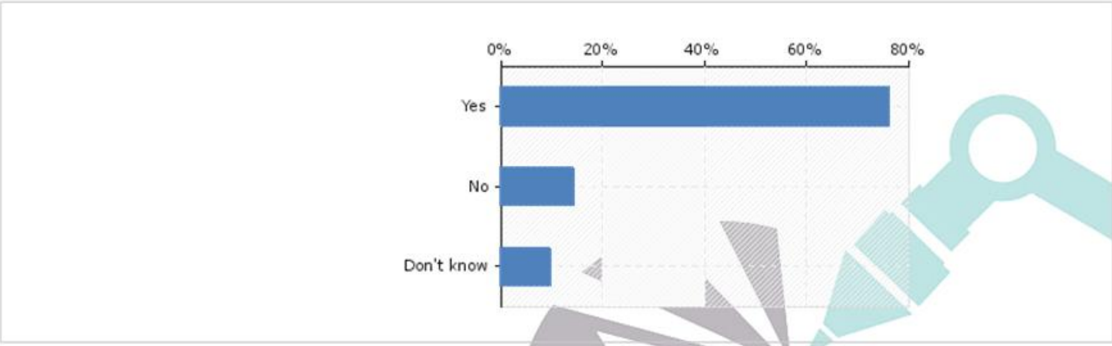
A majority of 82% (18) thought that their employees would benefit from more knowledge/training about the use of 3D printing, while 9% (2) answered no and 9% (2) did not know. As with robotics, the answers indicate that not only future workers, but also existing employees could have an interest in gaining additional training and skills.

Would your employees benefit from more knowledge/training about the use of 3D printing? (n = 22)



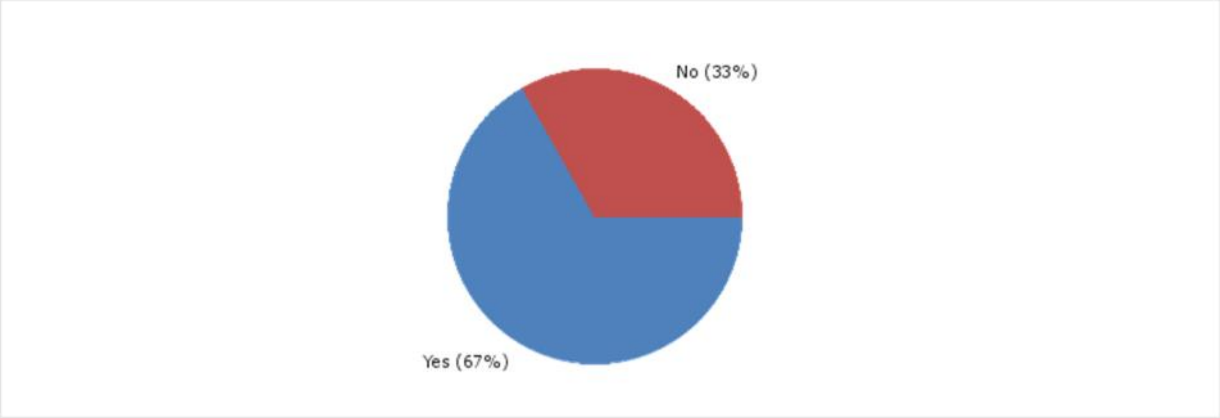
Most, 76% (16), also thought that their company will likely make use of 3D printing in the future, while 14% (3) did not think so and 10% (2) did not know. The fact that a majority of the surveyed SMEs think it likely that they will use such technologies in the future shows that demand for 3D printing and related skills will likely increase in the future.

Do you think that your company will likely make use of 3D printing in the future?(n = 21)



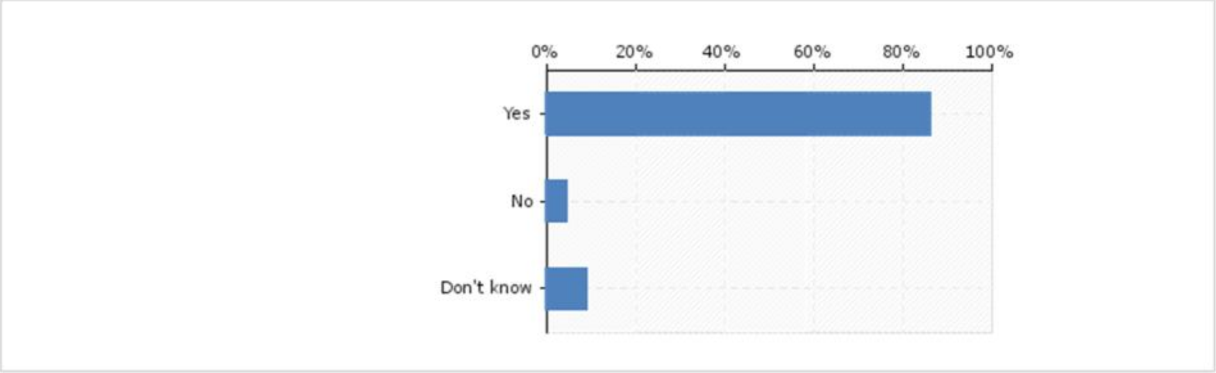
Further, 67% (14) thought that the use of 3D printing would improve their competitiveness and/or reduce costs, while 33% (7) thought this unlikely. Such an opinion further strengthens the probability of future demand for 3D printing and related skills.

Do you think use of 3D printing would improve your competitiveness and/or reduce costs? (n = 21)



A majority of 86% (19) thought that schools and educational institutions should provide (more) 3D printing skills/knowledge training, while 5% (1) did not think so and 9% (2) did not know. As with robotics, the majority in favor of more such training in schools and educational institutions also confirms the need for online courses and materials that can be used and adapted to suit specific curricula and training.

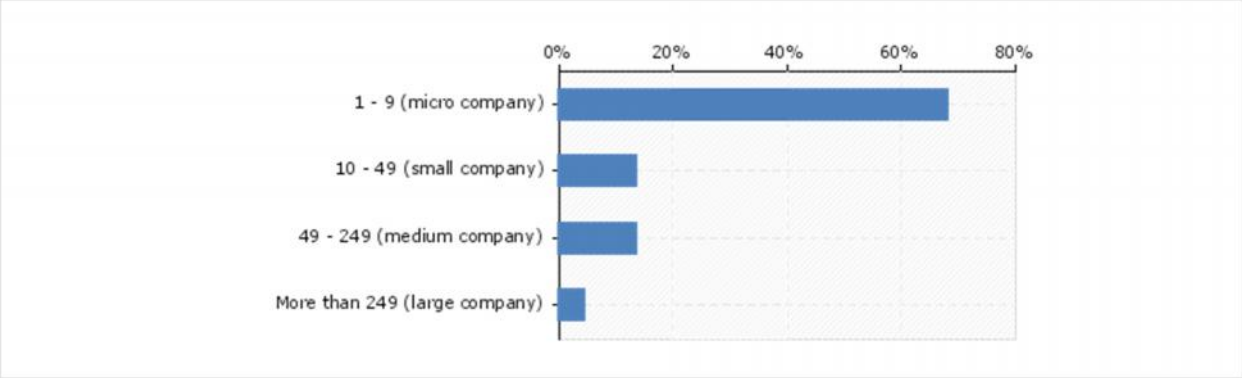
Do you think that schools and educational institutions should provide (more) 3D Printing skills/knowledge training? (n = 22)



SMEs characteristics

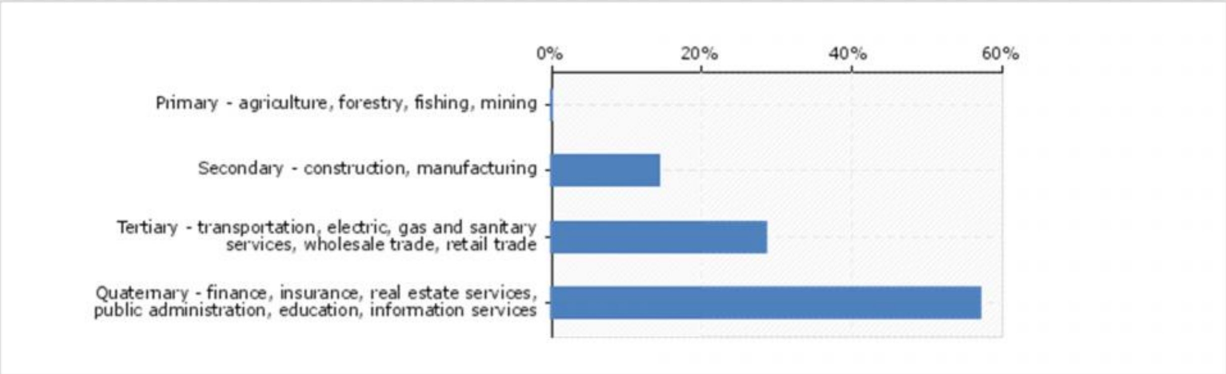
If we look at the characteristics of the SMEs whose representatives have participated in the survey, we can see that we had 68% (15) of micro companies with 1-9 employees, 14% (3) of small companies with 10-49 employees, 14% (3) of medium companies with 49-249 employees and 5% (1) of large companies with more than 249 employees.

How many people does your company employ?(n = 22)



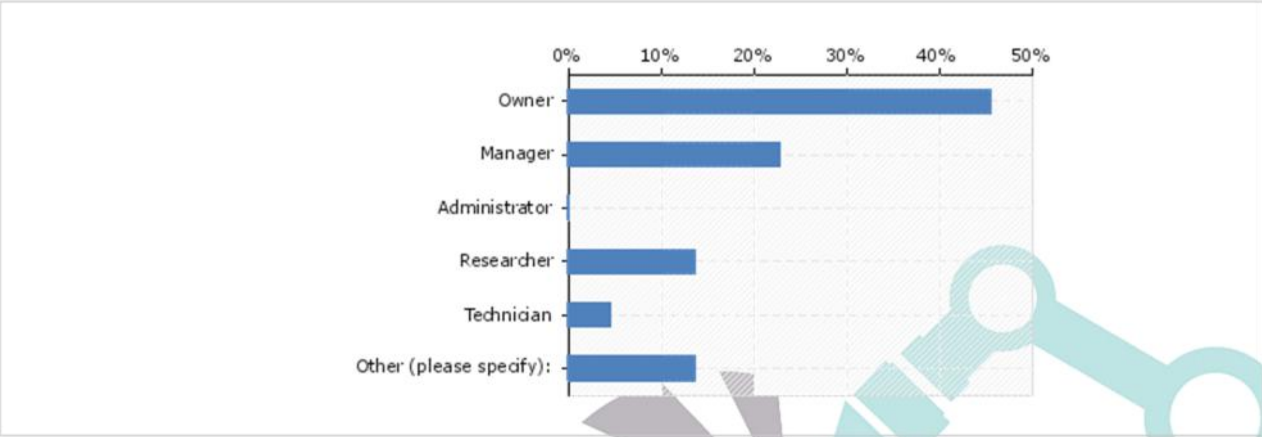
Regarding the organizational sector that the SMEs belong to, we had 14% (3) from the Secondary sector (construction, manufacturing), 29% (6) from the Tertiary (transportation, electric, gas and sanitary services, wholesale trade, retail trade), and 57% (12) from the Quaternary - finance, insurance, real estate services, public administration, education, information services).

Please indicate the organisational sector of your company:(n = 21)



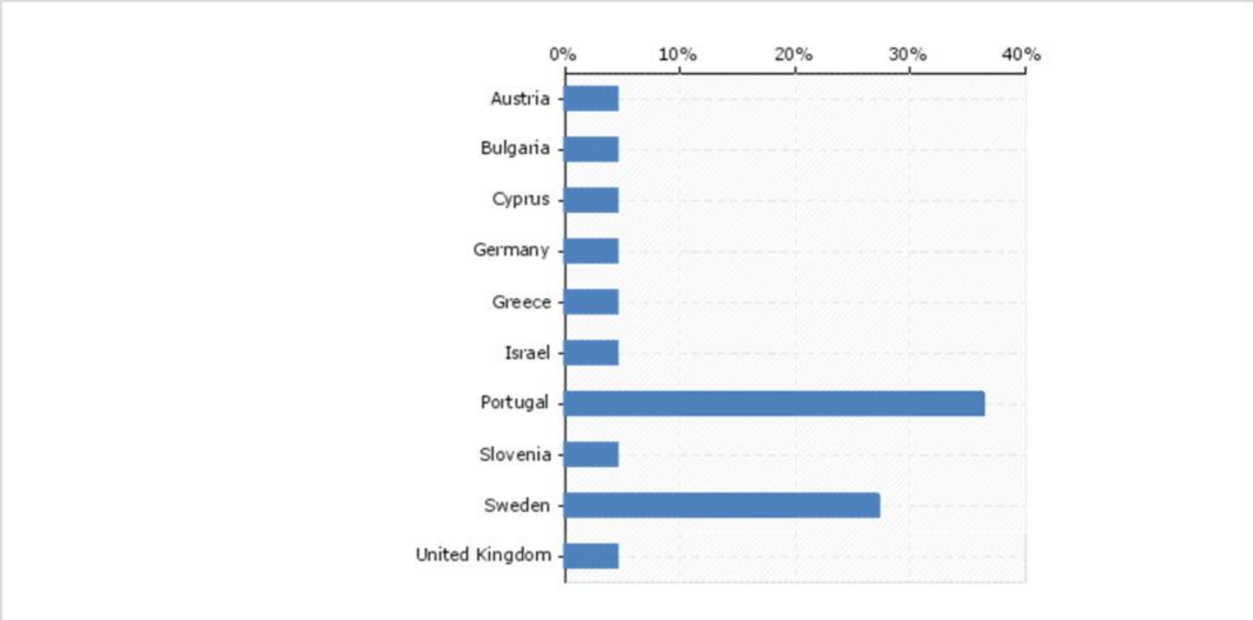
The position of the respondents in the SMEs was owner for 45% (10), manager for 23% (5), researcher for 14% (3), technician for 5% (1) and 14% (3) for other.

What is your position in the company? (n = 22)



The geographical location of the company was 64% (8) for Portugal, 27% (6) for Sweden, and 5% (1) each from Austria, Bulgaria, Cyprus, Germany, Greece, Israel, Slovenia and the UK.

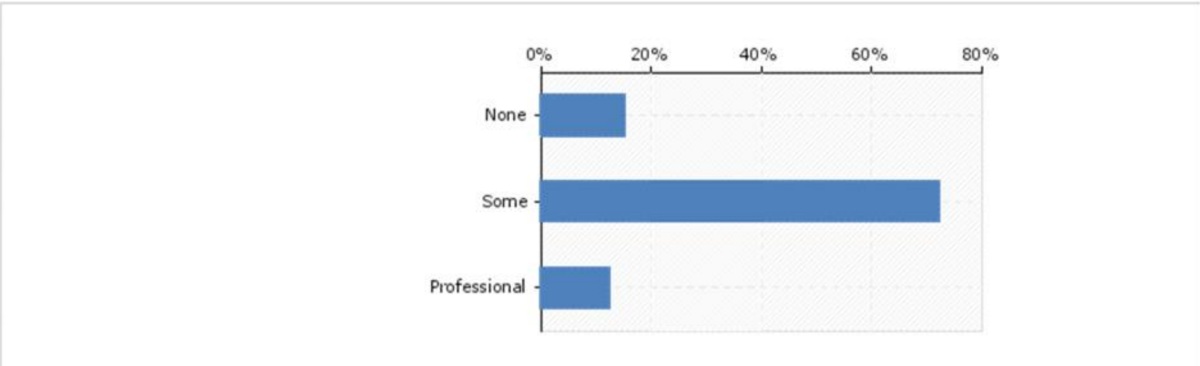
In which country is your company based?(n = 22)



Individuals on robotics

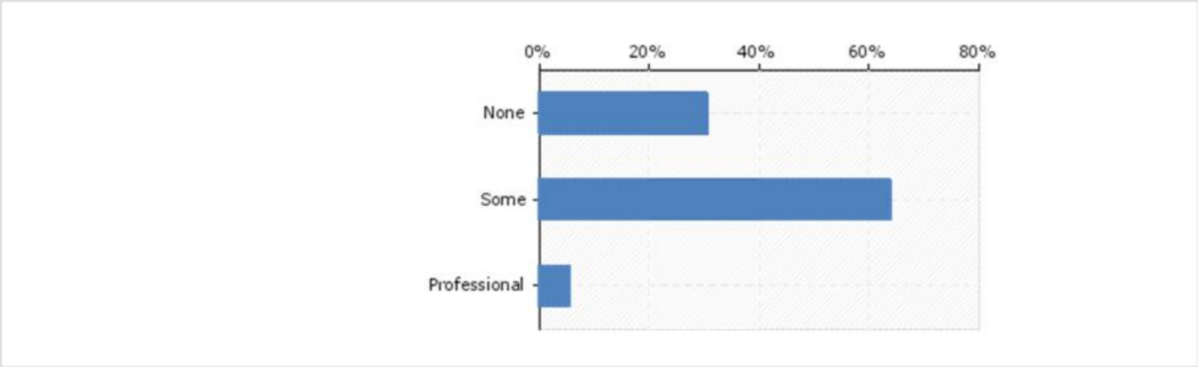
We first asked the individuals whether they have any knowledge/skills in electronics, programming or engineering. 15% (11) answered they had none, 72% (52) had some knowledge, while only 13% (9) had professional knowledge or skills in these fields. The answers show that the individuals interested in our survey are mostly ones that already have some general knowledge or skills related to robotics and 3D printing.

Do you have any knowledge/skills in electronics, programming or engineering? (n = 72)



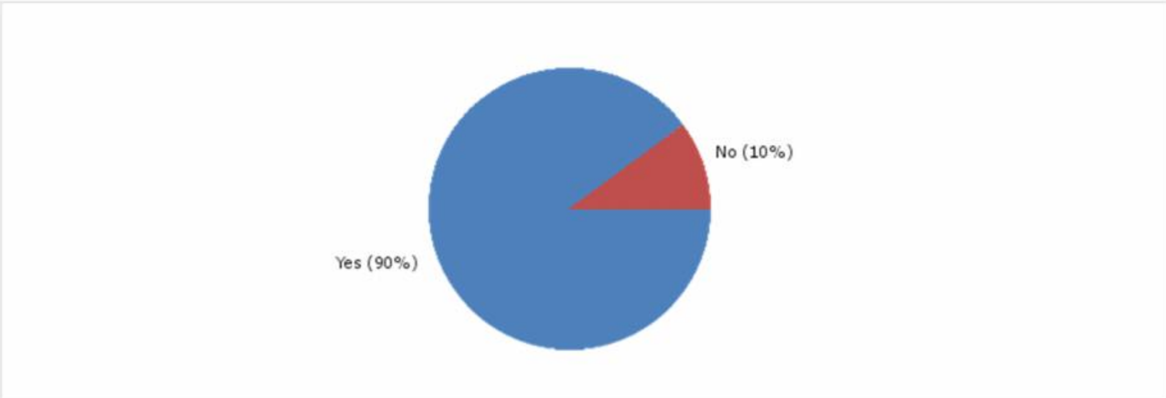
Regarding knowledge specifically of automation and robotics, 31% (22) had none, 64% (46) has some and only 6% (4) had professional knowledge. This shows that both people who as yet have no knowledge and people who have some knowledge of robotics and automation are interested in the subject.

What is your knowledge of automation and robotics? (n = 72)



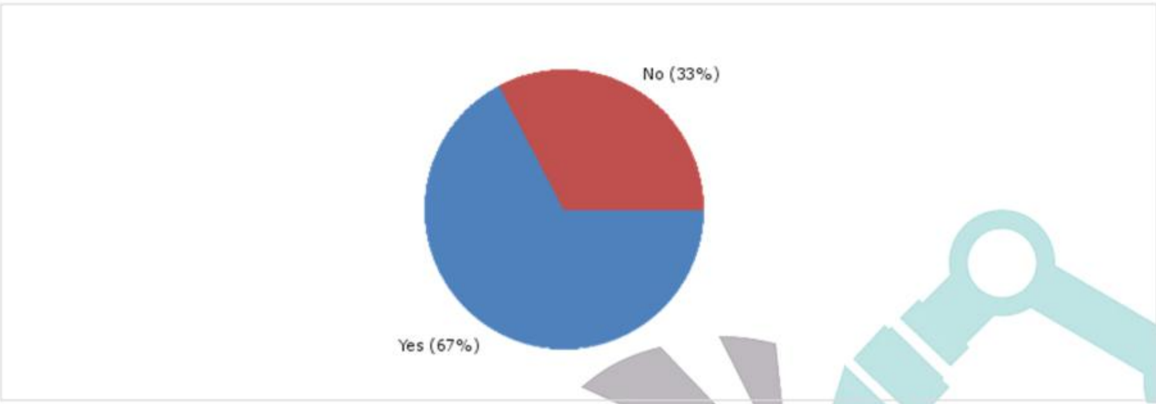
A majority of 90% (44) thought that in the future, knowledge of robotics could give them a professional advantage in job seeking or their work, while 10% (5) thought that it would not. Given the answer, we can expect that the respondents will be interested in gaining further knowledge of robotics, and that they believe these skills will become more important in the future.

Do you think that in the future, knowledge of robotics could give you a professional advantage in job seeking/your work?(n = 49)



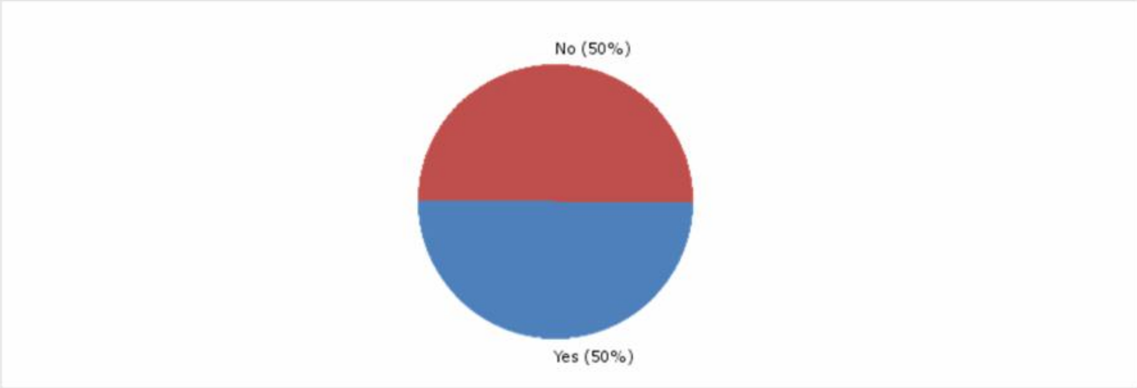
Most had some contact with robotics subjects and knowledge at school or in training, while 33% (16) did not.

Have you had any contact with robotics subjects/knowledge at school/in training? (n = 49)



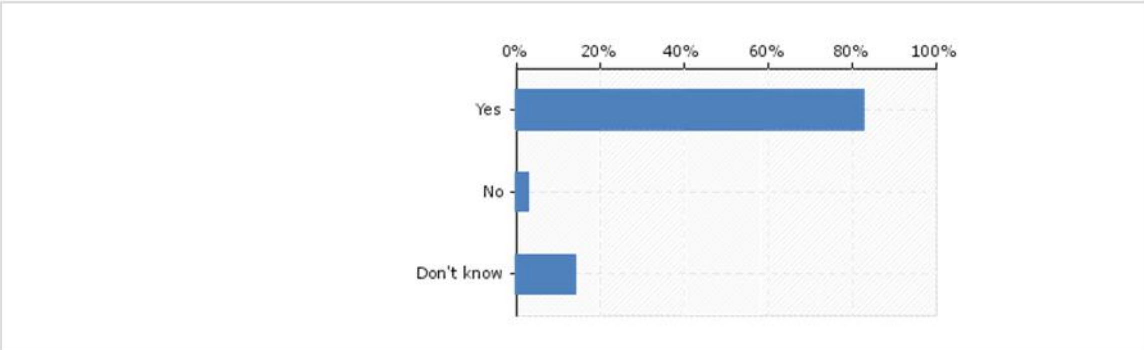
Regarding whether they had taken any course or modules about robotics, 50% (24) had and 50% (24) had not.

Have you taken any course/module about robotics (online and/or offline)?(n = 48)



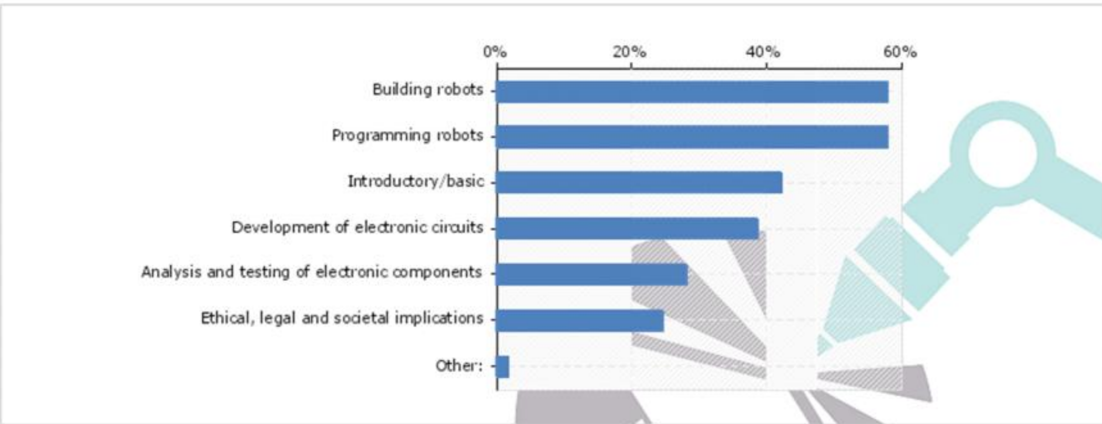
A majority of 83% (58) would consider taking a course/module about robotics if it were available for free, while 3% (2) and 14% (10) did not know. Regardless of whether they had already had contact with robotics knowledge and school and have taken any previous courses or modules about robotics, most individual respondents would still be interested in taking a free course or module on robotics.

If available for free, would you consider taking a course/module about robotics? (n = 70)



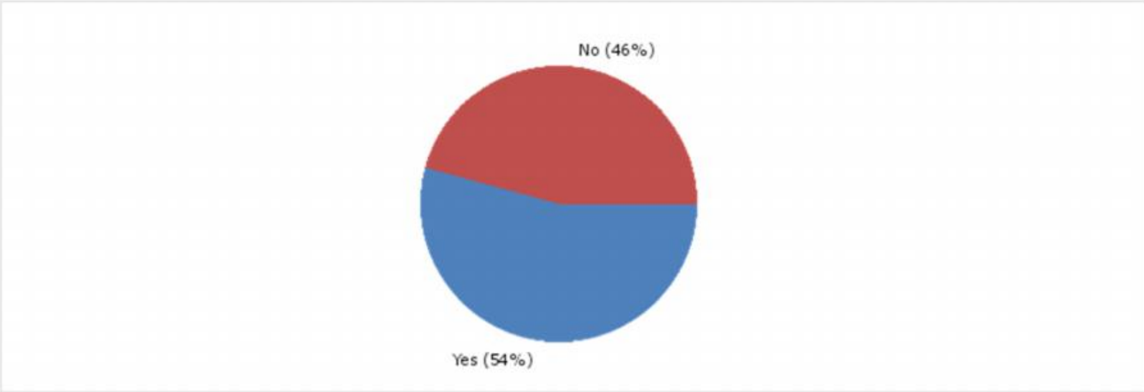
We also asked them whether there is an area or subject in robotics of which they would prefer to learn more about. Most respondents were interested in building and programming robots (58%, 33), in introductory and basic knowledge of robotics (42%, 24), and in development of electronic circuits (39%, 22). Less than a third of respondents were interested in analysis and testing of electronic components (28%, 16) and in the ethical, legal and societal implications of robotics (25%, 14). One respondent additionally listed new usages of robots specifically in emotive relation with people. Given the answers, more than half of the respondents would be interested

Is there an area of robotics/a subject that you would prefer to learn about?(n = 57)
Multiple answers are possible



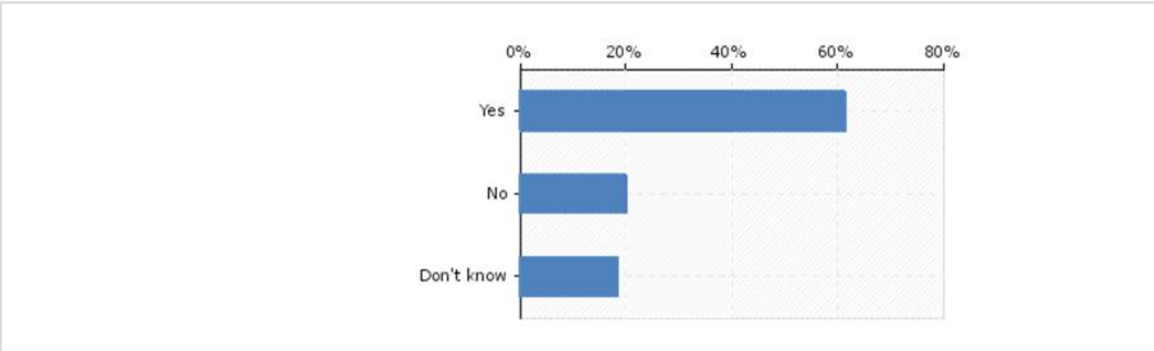
We further asked them whether they could envisage their work being carried out by a robot. A little more than half, 54% (38) could do so, while 46% (32) could not. Despite some tasks and jobs being automated, we can expect that there will still be more demand for workers who will design, produce, maintain and operate robotic systems.

Could you envisage your work being carried out by a robot? (n = 70)



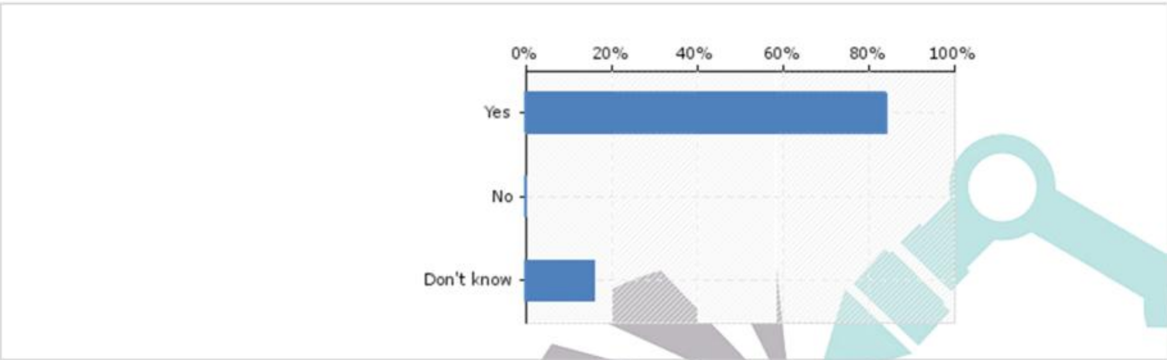
More than two thirds, 42% (61) also thought it likely that their work will involve robotics/robots in the future, while 20% (14) thought it unlikely and 19% (3) did not know. Again, the expectation that their work will likely involve robotics and robots in the future indicates additional needs and demand for knowledge and skills training and education in the subject.

Do you think it likely that you work will involve robotics/robots in the future? (n = 70)



A majority of 84% (58) thought schools and educational institutions should provide more robotics skills and knowledge training, while 16% (11) did not know.

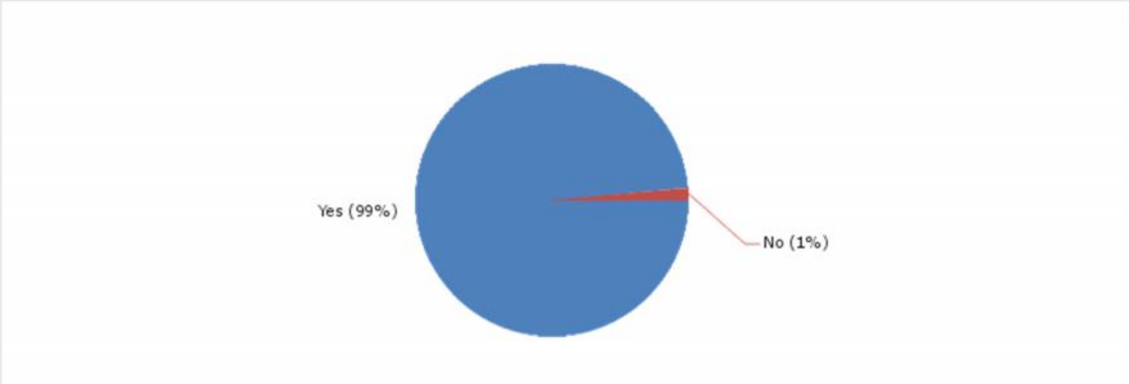
Do you think that schools and educational institutions should provide (more) robotics skills/knowledge training? (n = 69)



<u>Individuals on 3D printing</u>

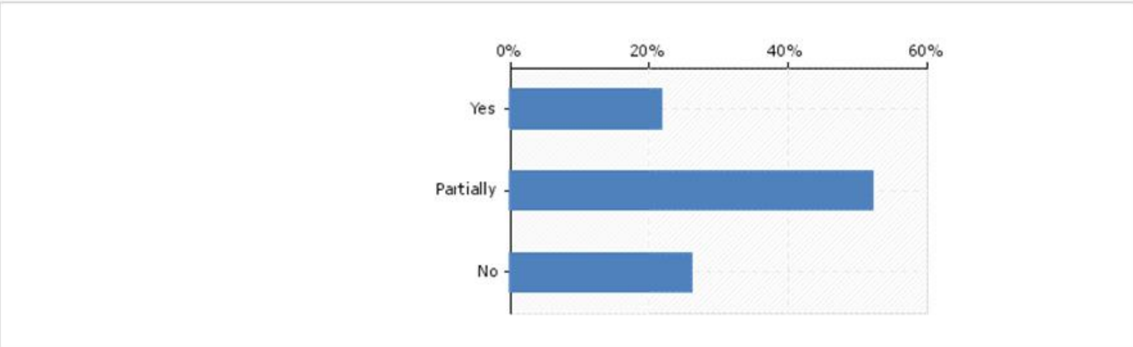
Practically all respondents (99%, 69) except one have heard of 3D printing.

Have you ever heard of 3D printing?(n = 70)



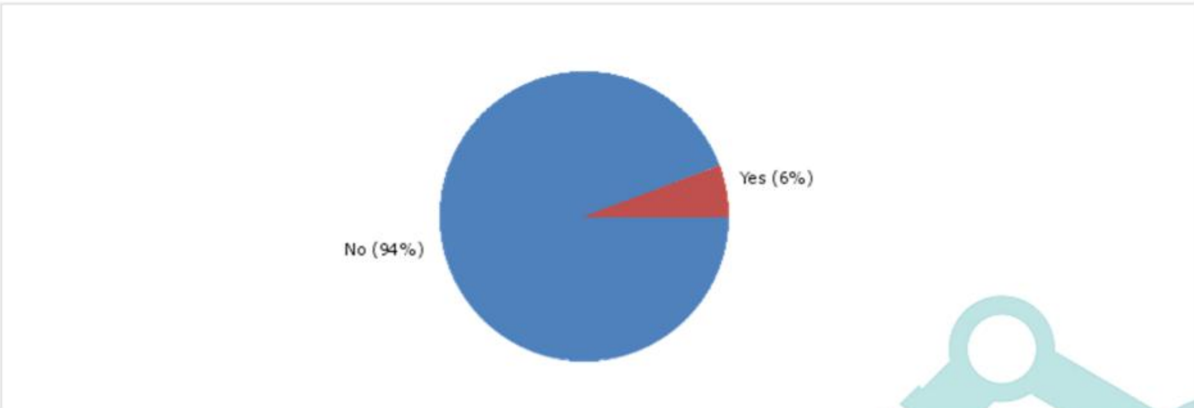
Regarding the use of 3D printing, 22% (15) answered that they knew how to use 3D printing, 52% (36) partially knew how to use it, while 26% (18) did not know how to use it. Given that a majority of the individual respondents had only partial or no knowledge of 3D printing use, this indicates a need and possible demand for additional, easily accessible online courses and training.

Do you know how to use 3D printing? (n = 69)



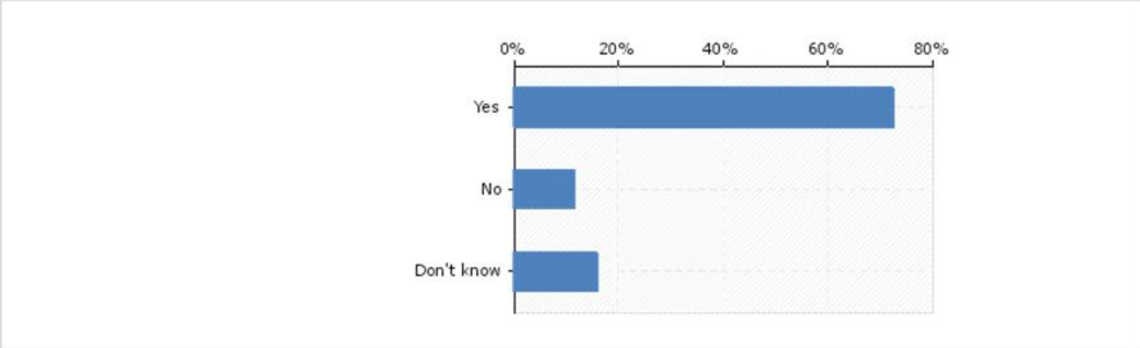
A majority of the respondents, 94% (65) have not yet taken any course or module about 3D printing, while only 6% (4) had. Given this answer, we can again see a need for more freely and easily accessible courses and training on the topic of 3D printing.

Have you taken any course/module about 3D printing?(n = 69)



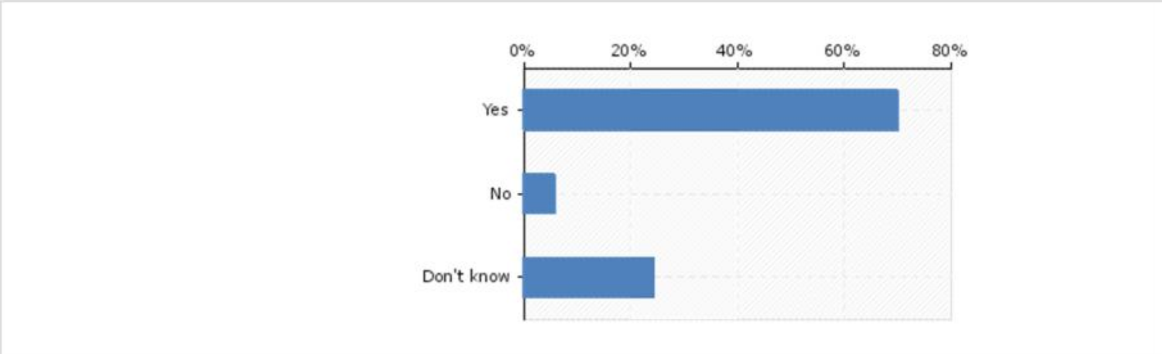
More than two thirds, 72% (50) thought that in the future, knowledge of 3D printing could give them a professional advantage in job seeking or their work, while 12% (8) did not think so. Since a majority see a professional advantage in more such knowledge, we can expect a rise in the demand for courses providing such knowledge and skills.

Do you think that in the future, knowledge of 3D printing could give you a professional advantage in job seeking/your work?(n = 69)



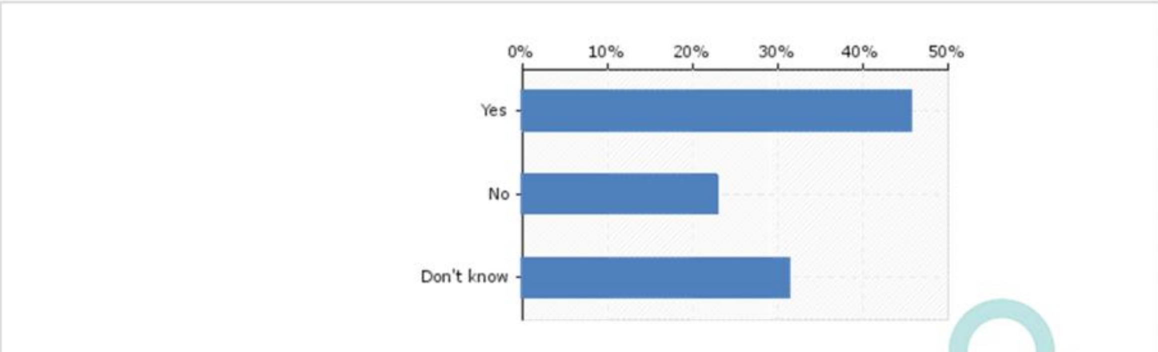
If a course or module about 3D printing were available for free, a majority of 70% (49) would consider taking it, while 6% (4) said they would not take it, and 24% (17) did not know if they would take it. The answer clearly shows a need for more free courses and training on the topic.

If available for free, would you consider taking a course/module about 3D printing? (n = 70)



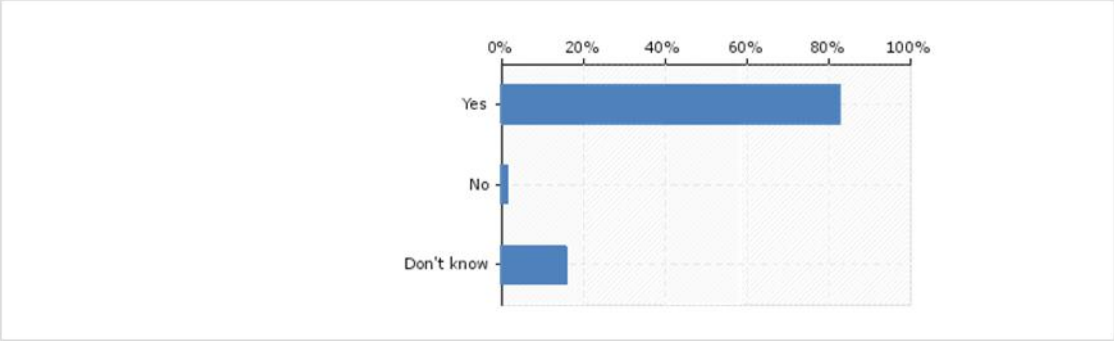
A little less than half, 46% (32) thought it likely that their work will involve 3D printing in the future, while 23% (16) thought it unlikely and 31% (22) did not know. This further confirms the need and possibly a growing future demand for such training and knowledge.

Do you think it likely that you work will involve 3D printing in the future? (n = 70)



A majority of the individual respondents, 84% (58) thought that schools and educational institutions should provide more 3D printing skills and knowledge training, while 16% (11) said that they do not know. The majority of affirmative responses further indicate a need and future growing demand for more training and courses on the topic.

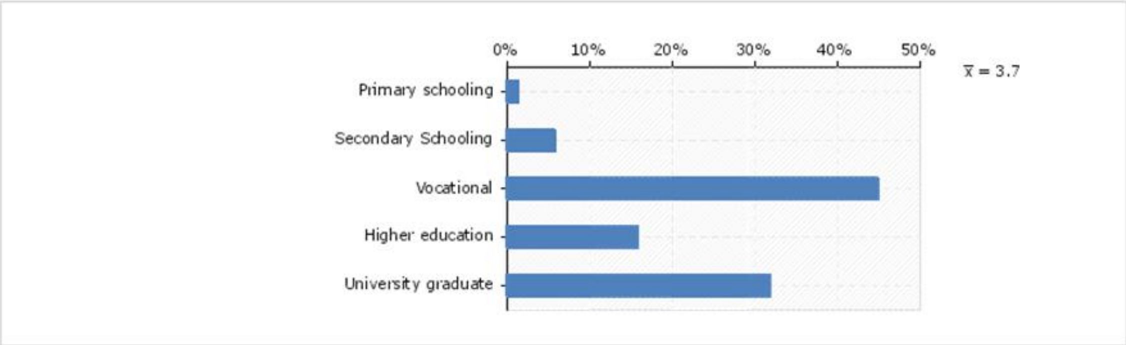
Do you think that schools and educational institutions should provide (more) 3D Printing skills/knowledge training? (n = 70)



Characteristics of individual respondents

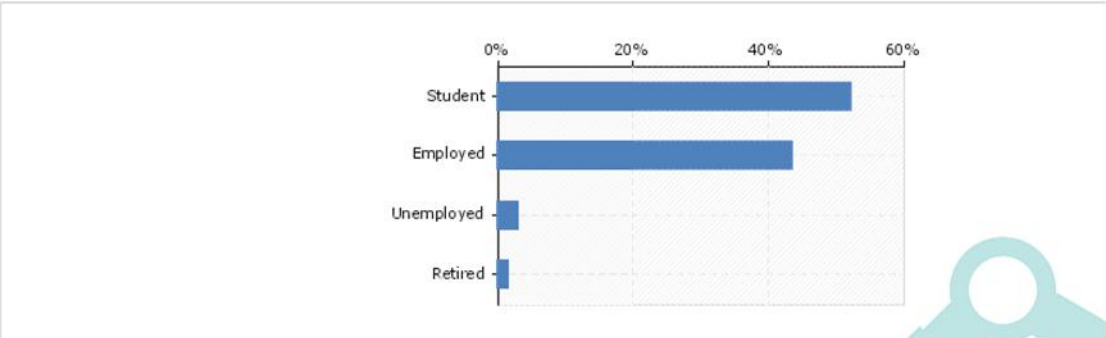
Looking at the characteristics of our respondents, we first asked them about the highest degree or level of schooling they have completed. A majority had attained a vocational degree (45%, 31), more than a third (32%, 22) were University graduates, 16% (11) had attained higher education, while 6% (4) had secondary schooling and 1% (1) had primary schooling.

What is the highest degree or level of schooling you have completed?(n = 69)



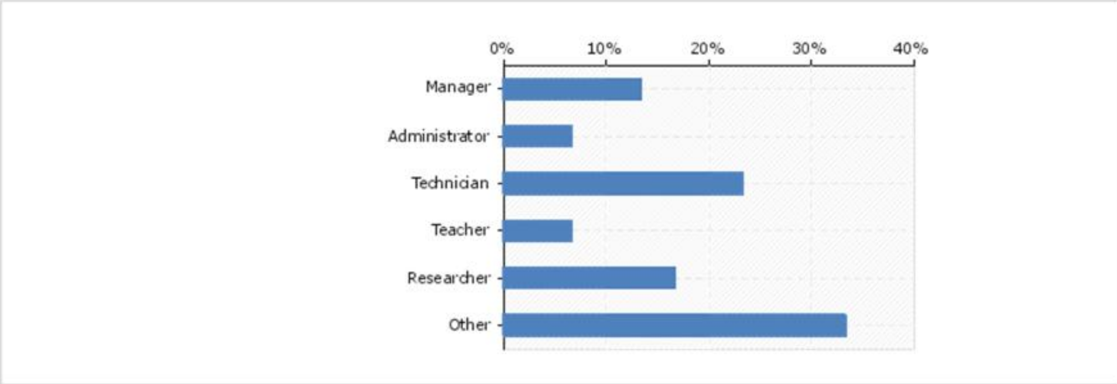
Regarding their employment status, most were either students (52%, 36) or employed (43%, 30), while 3% (2) were unemployed and 1% (1) were retired. The answers indicate that both students and already employed individuals are interested in gaining (additional) skills in the areas of robotics and 3D printing, which means a need for introductory and advanced knowledge and training.

What is your employment status?(n = 69)



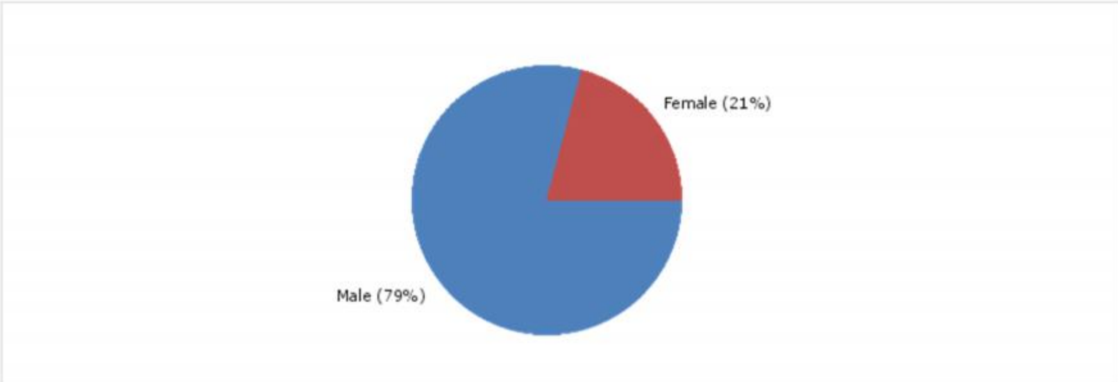
We also asked about their job classification. Most selected other (33%, 10), technician (23%, 7) and researcher (17%, 5). The rest selected manager (13%, 4), and administrator and teacher (7%, 2 for each).

What is your job classification?(n = 30)



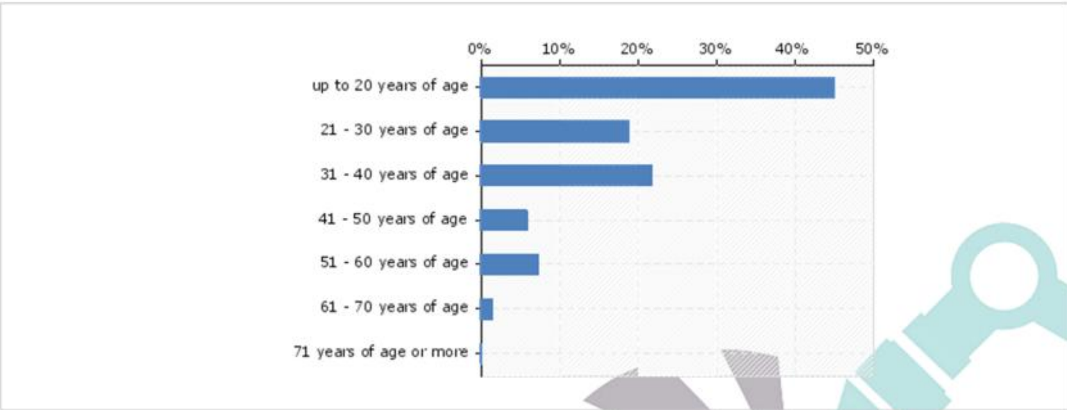
Regarding gender, a majority were male (79%, 53) and 21% (14) were female. The answers indicate that new technology topics such as robotics and 3D printing still mostly attract males, which means that finding means and incentives to attract more females to the topics is another open issue that would be worth pursuing.

What is your gender?(n = 67)



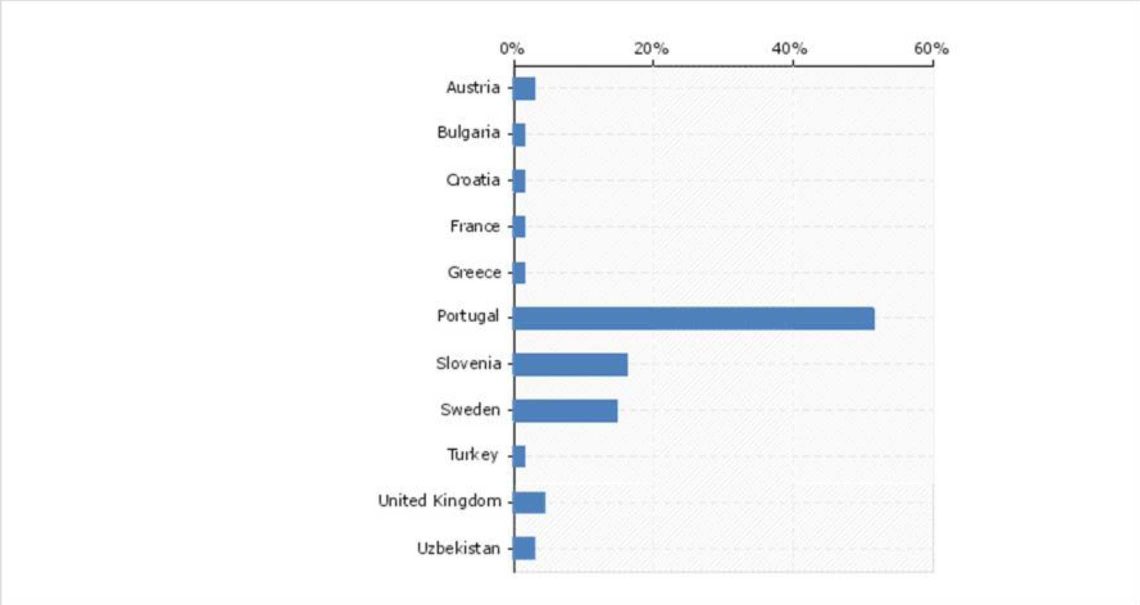
In terms of age groups, almost half, 45% (31) were up to 20 years of age, 22% (15) were 31-40 years of age, and 19% (13) were between 21-30 years old. The rest were between 51-60 (7%, 5), 41-50 (6%, 4) and 61-70 (1%, 1). Given that our respondents were mostly below the age of 40, another open issue would be finding ways to attract older people to the topic of new technologies.

In which age group do you belong?(n = 69)



Regarding the country where they live, a majority of individual respondents were from Portugal (51%, 35), Slovenia (16%, 11) and Sweden (15%, 10). The rest were from the UK (4%, 3), Austria (3%, 2), and Uzbekistan (3%, 2). The remaining respondents were from Bulgaria, Croatia, France, Greece and Turkey (1%, 1 for each).

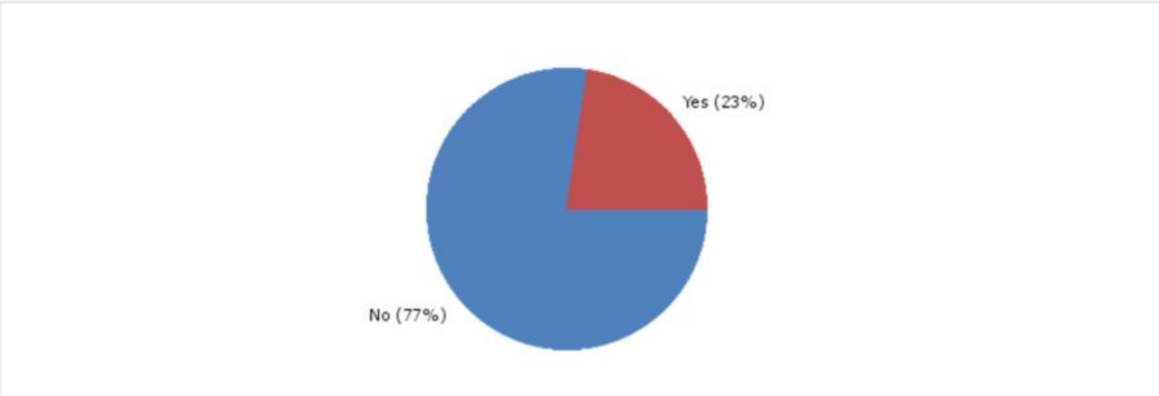
In which country do you live?(n = 68)



Vocational education and training institutions on robotics

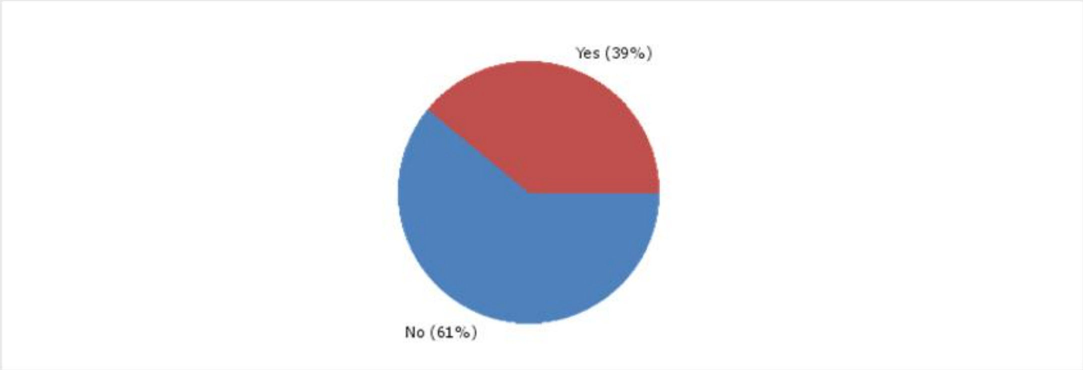
Regarding robotics, we asked the representatives of the institutions whether they offer any stand-alone robotics courses, and only 23% (5) answered that they do, while 77% (17) answered that they do not. The answers indicate that there is a need for additional stand-alone courses on the topic of robotics that can be adapted by institutions to suit their own curricula and needs.

Does your institution offer any stand-alone robotics courses?(n = 22)



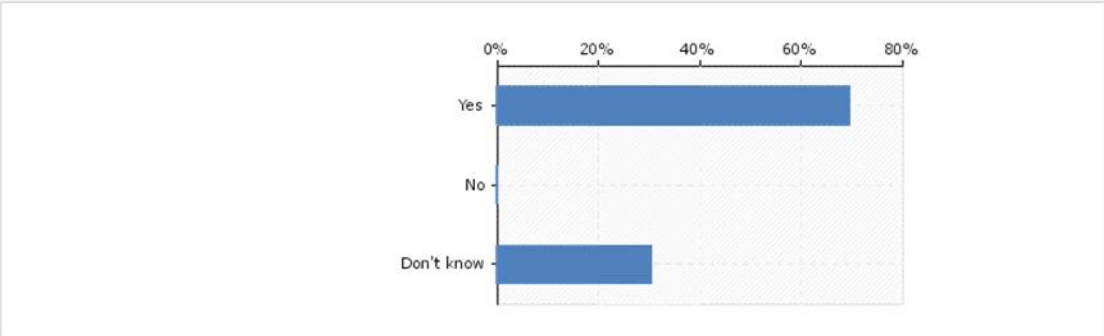
We further inquired whether they offer any robotics modules within existing courses, and this time 39% (9) answered that they do, and 61% (14) answered that they do not. While more institutions offer robotics knowledge and skills within existing courses, there is still an evident lack and need for more such courses, especially those that can be adapted and used by institutions within their existing programs.

Does your institution offer any robotics modules within existing courses?(n = 23)



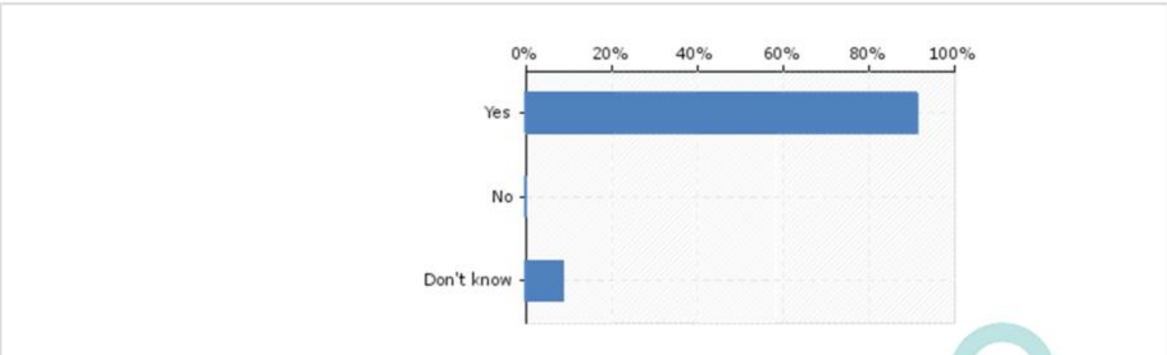
Regarding whether they are considering to offer such courses or modules in the future, 70% (16) answered that they do have such plans, while 30% (7) did not know. The answers again indicate a growing need and demand for robotics education courses.

Is your institution considering to offer such courses/modules in the future? (n = 23)



A majority of 91% (21) were of the opinion that schools and educational institutions should provide (more) robotics skills/knowledge training, while 9% (2) did not know. Considering the majority agreement with the need for more such training, we can expect that new, adaptable courses will be in greater demand in the future.

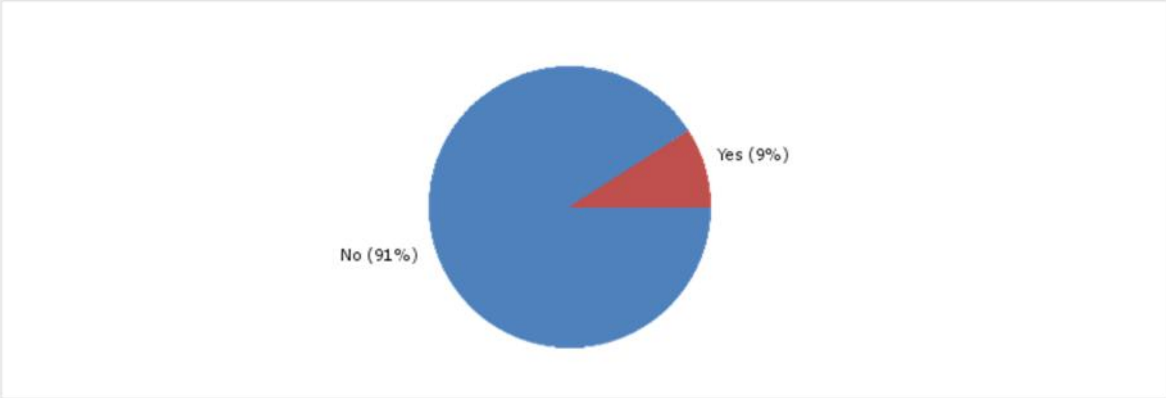
Do you think that schools and educational institutions should provide (more) robotics skills/knowledge training? (n = 23)



Vocational education and training institutions on 3D printing

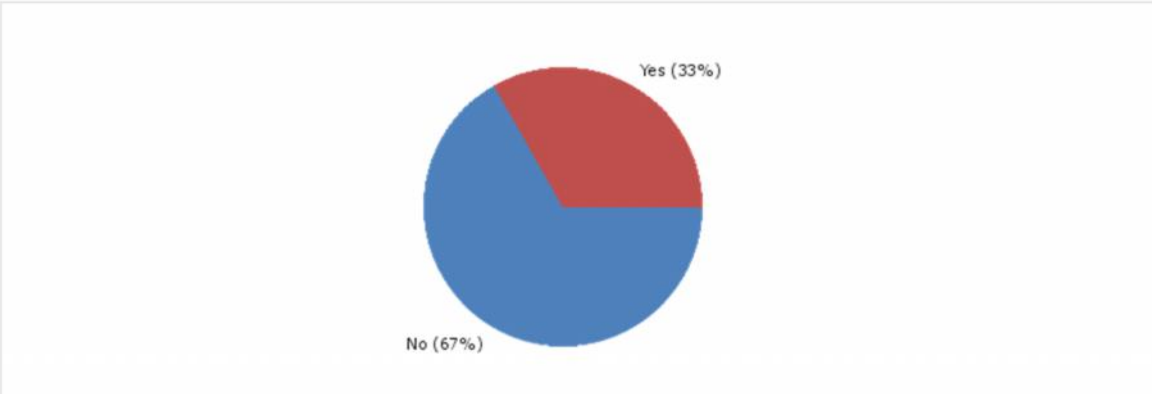
Regarding 3D printing, we asked the representatives of the institutions whether they offer any stand-alone courses about 3D printing and only 9% (2) answered that they do, while 91% (20) answered that they do not. As with robotics, we can see an even greater need for additional courses on 3D printing.

Does your organization offer any stand-alone courses about 3D printing? (n = 22)



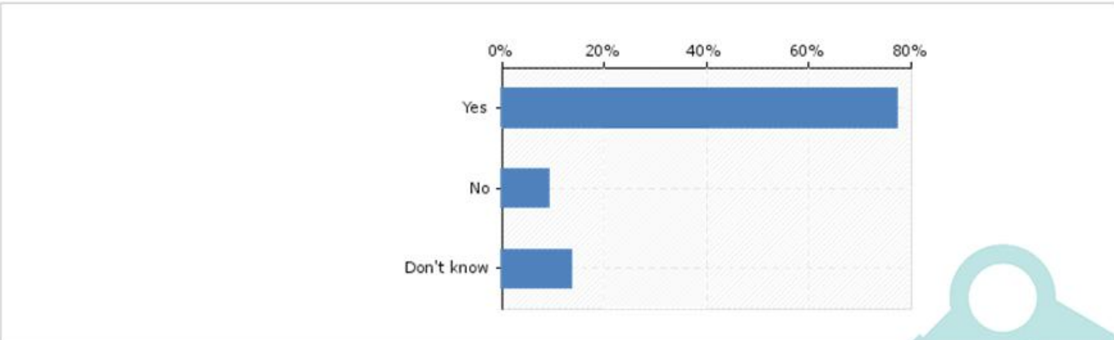
We further inquired whether they offer any modules about 3D printing within existing courses, and this time 33% (7) answered that they do, and 67% (14) answered that they do not. Again, there is the indication of a clear need for more easily accessible courses on 3D printing.

Does your organization offer any modules about 3D printing within existing courses? (n = 21)



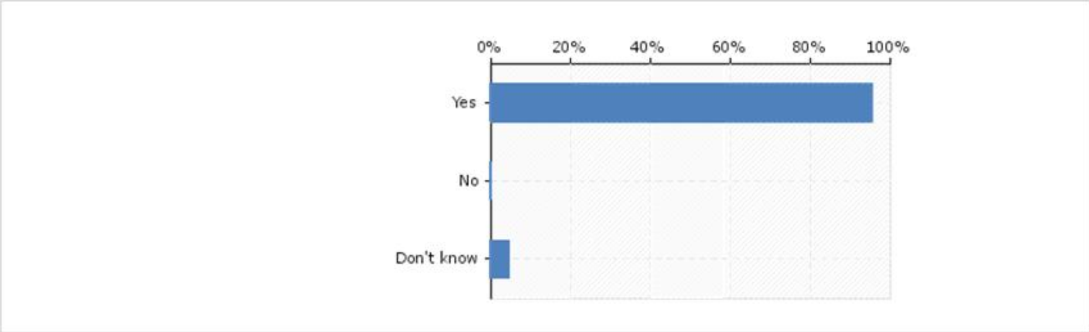
Regarding whether they are considering to offer such courses or modules in the future, 77% (17) answered that they do have such plans, 9% (2) answered that they do not, and 14% (3) did not know. Future plans for offering such courses indicate a growing demand for adaptable courses.

Is your organization considering to offer such courses/modules in the future? (n = 22)



A majority of 95% (21) were of the opinion that schools and educational institutions should provide (more) 3D printing skills/knowledge training, while 5% (1) did not know. Considering the majority agreement with the need for more such training, we can expect that new, adaptable courses will be in greater demand in the future.

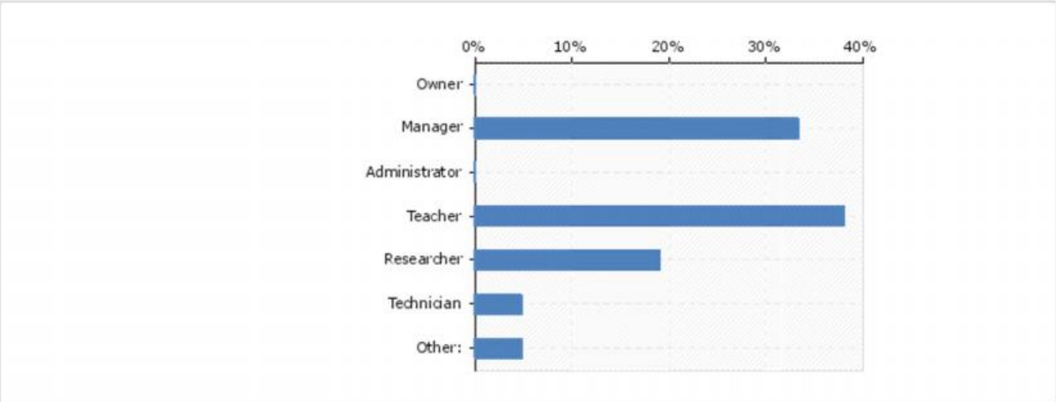
Do you think that schools and educational institutions should provide (more) 3D Printing skills/knowledge training? (n = 22)



Characteristics of vocational education and training institutions

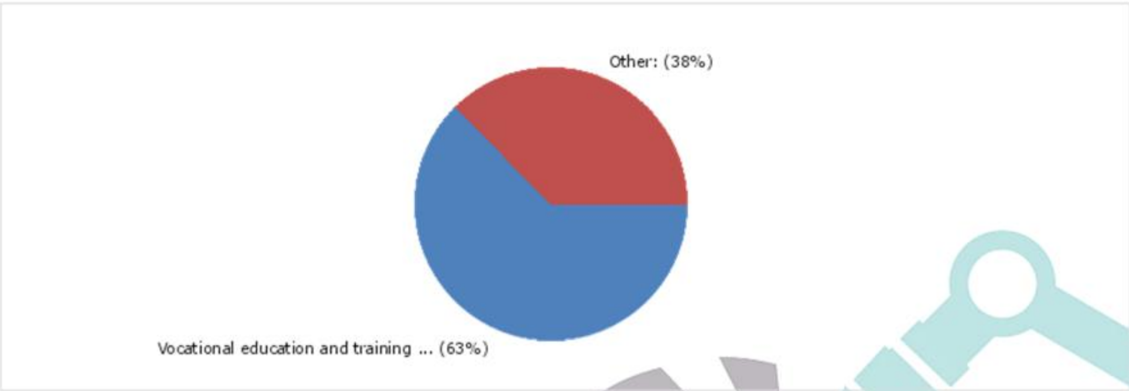
Regarding the characteristic of the respondents and institutions, a majority of the representatives held the position of teacher (38%, 8), manager (33%, 7) or researcher (19%), while the others listed technician or other (5%, 1 for each).

What is your position in the organization? (n = 21)



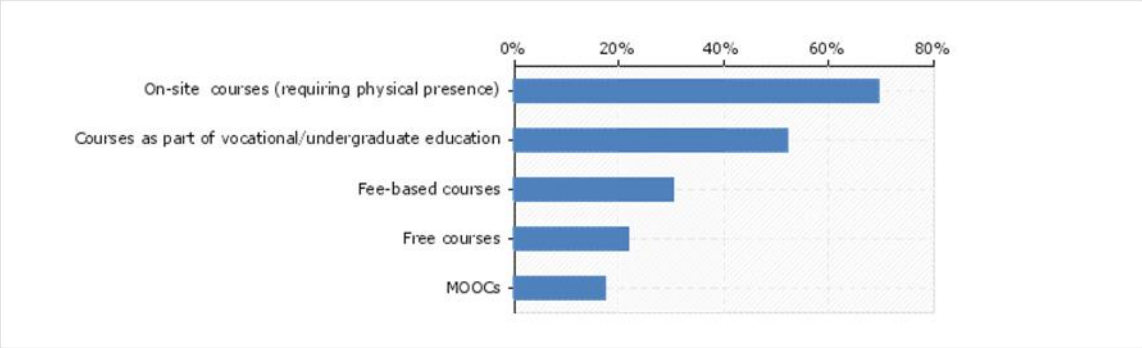
Most 63% (15) of the representatives such institutions listed that their institution is a vocational education and training institution, while 38% (9) listed another type of institution (such as senior citizen education, lifelong learning center, college, university, etc.).

Please specify the type of your institution:(n = 24)



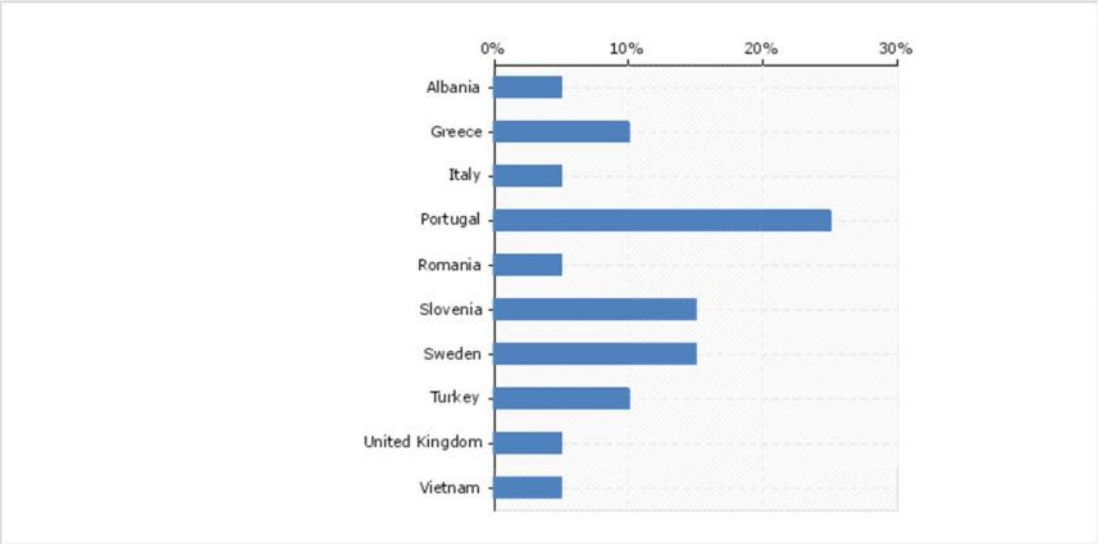
A majority of the institutions provide on-site courses that require physical presence (70%, 16) and courses that are part of a vocational/undergraduate education (52%, 12). Only 17% (4) offer MOOCs, 22% (5) offer courses that are free and 30% (7) offer courses that are fee-based.

What types of courses does your institution offer?(n = 23)
Multiple answers are possible



Regarding the geographical location of the institutions, most were from Portugal (25%, 5), Slovenia and Sweden (15%, 3 for each), Greece and Turkey (10%, 2 for each), and the rest from the UK, Italy, Albania, Romania and Vietnam (5%, 1 each).

In which country is your organization based?(n = 20)



<u>List of open courses on introductory robotics</u>

In Europe

University of Sheffield: Building a Future with Robots (FutureLearn)
https://www.futurelearn.com/courses/robotic-future

University of Reading: Begin Robotics (FutureLearn)
https://www.futurelearn.com/courses/begin-robotics

ETH Zurich: Autonomous Mobile Robotics (edX)
https://www.mooc-list.com/course/amrx-autonomous-mobile-robots-edx

Outside of Europe

COURSERA (University of Pennsylvania): Robotics Specialization
https://www.coursera.org/specializations/robotics

Columbia University (NY): Robotics (edX)
https://www.edx.org/course/robotics-columbiax-csmm-103x#!

University of Pennsylvania: Robotics - Fundamentals (edX)
https://www.edx.org/course/robotics-fundamentals-pennx-robo1x

Queensland University of Technology: Introduction to Robotics (FutureLearn)
https://moocs.qut.edu.au/learn/introduction-to-robotics-july-2016

Queensland University of Technology: Introducing robotics: robotics and society (FutureLearn)
https://www.futurelearn.com/courses/robotics-and-society

Queensland University of Technology: Introducing Robotics - Making Robots Move (FutureLearn)
https://www.futurelearn.com/courses/making-robots-move

Queensland University of Technology: Introducing Robotics - Build a Robot Arm (FutureLearn)
https://www.futurelearn.com/courses/build-a-robot-arm

Swinburne University of Technology: Mobile Robotics (Open2Learn)
https://www.open2study.com/courses/mobile-robotics

<u>List of open courses on introductory 3D printing</u>

In Europe

ALISON: Learn how to use a 3D printer
https://alison.com/course/how-to-use-a-3D-printer

Computer Training Wales company: 3D printing course.
http://www.computertrainingwales.co.uk/courses/computer-aided-design/3d-printing-training.html

GetReady4 3D company. 3D Printing.
http://www.sabe-online.com/products/3d-printing

Outside of Europe

COURSERA (University of Illinois - Illinois Makerlab, Autocad, Ultimaker): 3D Printing Specialization
https://www.coursera.org/specializations/3d-printing

UDEMY: How to Start 3D Printing at Home - Even Without a 3D Printer
https://www.udemy.com/introduction-to-3d-printing-at-home/

UDEMY: The Fundamentals Of 3D Printing
https://www.udemy.com/fundamentals-of-3d-printing/

STRATASYS : 3D printing curriculum - introduction to 3D Printing
http://www.stratasys.com/industries/education/educators/curriculum/introduction-to-3d-printing

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