CUIEET

Gijón

Gijón, 25, 26 y 27 de junio 2018

XXVI Congreso Universitario de Innovación Educativa en las Enseñanzas Técnicas

Escuela Politécnica de Ingeniería de Gijón

LIBRO DE ACTAS

Universidad de Oviedo
Universidá d'Uviéu
University of Oviedo

LIBRO DE ACTAS DEL

XXVI Congreso Universitario de Innovación Educativa

En las Enseñanzas Técnicas

25-27 de junio de 2018

Escuela Politécnica de Ingeniería de Gijón

UNIVERSIDAD DE OVIEDO

ISBN: 978-84-17445-02-7

DL: AS 1893-2018

Effect of Industry 4.0 on Education Systems: An Outlook

Álvarez Gil, Nicolás[a], Rosillo Camblor, Rafael[b], Ponte Blanco, Borja[c], López Brugos, José Antonio[d]

[a]Department of Business Administration, University of Oviedo (uo226901@uniovi.es), [b] Department of Business Administration, University of Oviedo (rosillo@uniovi.es), [c]Department for People and Organisations, The Open University Business School (borja.ponte-blanco@open.ac.uk), [d] IT Department, University of Oviedo (brugos@uniovi.es)

Abstract

The aim of this paper is to analyze the main changes which manufacturing industry will face in the next years and to present different ways for training and preparing the workforce with the required skills. Both external factors, such as the increase in global competitiveness and the growing demand of flexible and customized outputs over standard products, and internal factors, like the new information and processing technologies, are driving the manufacturing industry to the Fourth Industrial Revolution, as well known as Industry 4.0. The shift of paradigm which it represents will affect the factories in the technical, organizational and communication level. Consequently, the labor force should be prepare to work in this new context. Learning factories, virtual learning environments and intelligent education systems are proposed as a way to train the future workforce for the Industry 4.0 frame.

Keywords: *Industry 4.0, education, learning factories, virtual learning environments, personalized-intelligent education system.*

Resumen

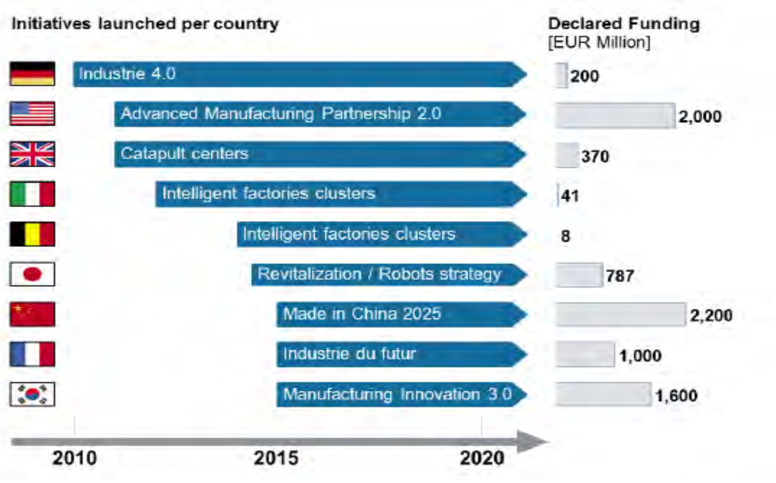
El objetivo de este artículo es analizar los principales cambios que afectarán al sector industrial en los próximos años, para posteriormente presentar diferentes métodos para educar y preparar a los futuros trabajadores con las competencias y habilidades necesarias. Factores externos como el incremento en la competitividad global y la creciente demanda de productos personalizados frente a aquellos estándares, y factores internos como las nuevas tecnologías de información y fabricación, están dirigiendo al sector de la producción hacia la Cuarta Revolución Industrial, también conocida como Industria 4.0. El *cambio de paradigma que supone afectará a las fábricas a nivel técnico, de comunicación y organizacional. Por tanto, los trabajadores deberán estar formados y preparados para trabajar en este nuevo contexto. "Learning factories", entornos virtuales de aprendizaje y sistemas de educación inteligentes y personalizados son presentados como potenciales métodos para entrenar a las personas para trabajar bajo el marco de la Industria 4.0.*

Palabras clave: *Industria 4.0, educación, learning factories, entornos virtuales de aprendizaje, sistemas de educación inteligentes personalizados*

Introduction

Nowadays, industrial globalization leads to an increase in global competitiveness and performance (Gehrke *et al.*, 2015), where standard products have a tendency to be customized according to clients demand (Roland Berger, 2015). In addition, the reduction of carbon footprint has become another cornerstone, due to the fact that it is crucial to reduce the impact environmental disruption to which the industrial production contributes, such as global climate warming, pollution, and the consumption in nonrenewable resources (Wang *et al.*, 2015). All these factors require the implementation and integration of cutting-edge technologies in the industry in order to improve the productivity, the efficiency and become more sustainable and flexible along the whole industrial chain process.

Figure 1. Worldwide initiatives and related investments announced



Source: Roland Berger (2015)

The aforementioned situation drives the manufacturing industry to the Fourth Industrial Revolution, as well called as Industry 4.0. It was launched in Germany and it is part of the Federal

Goverment´s high-tech strategy (BMBF, 2013). Furthermore, countries across the world have taken initiatives to be part of this industrial revolution, developing full-fledged national missions focused on advanced manufacturing technologies as *Advanced Manufacturing Partnership* 2.0 in USA, *Revitalization and Robots Strategy* in Japan, *Industry du Futur* in France or *Made in China 2025* in China, to name a few (Roland Berger, 2015).

Industry 4.0

The core idea of Industry 4.0 is to use the emerging information technologies to implement Internet of things and services. So, business process and engineering process are deeply integrated making production operate in a flexible, efficient, and green way with constantly high quality and low cost (Wang *et al*., 2015). Thus, Industry 4.0 represent a paradigm shift from the previous era of rigid, efficiency-focused and manual manufacturing to a more dynamic, agile and automated manufacturing (Roland Berger, 2015). It also marks a shift of focus from mass production to mass customization, enabled by the increase in the flexibility of the production. Flexibility means both "the flexibility for different production quantities as well as the flexibility to produce different types or different configured products with the same production systems without or with only very short set-up times" (Simons *et al*., 2017). Flexibility will also manifest in the ability to work remotely, which is very important regarding the transition from large-scale factories to small factories at decentralized locations (Roland Berger, 2015).

The two main forces driving the Fourth Industrial Revolution are Cyber Physical Systems (CPS) and the Internet of Things (IoT) (Gronau *et al*., 2017). CPS has been defined as the "systems in which natural and human made systems (physical space) are tightly integrated with computation, communication and control systems (cyber space)" (Baheri *et al.,* 2015). IoT is a "self-configuring, adaptative, complex network that interconnects "things" to the Internet through the use of standard communication protocols. The interconnected things have physical or virtual representations in the digital world […] and are uniquely identifiable" (Minerva *et al*., 2015). These two main forces enable the horizontal and the vertical integration.

The vertical integration is the merging of planning and development with the production (Gherke *et al*., 2015). It enables flexible and reconfigurable manufacturing systems by integrating the information of the physical world across different levels such as control, production management, manufacturing and corporate planning (Wang *et al*., 2015). On the contrary, horizontal integration is "the interconnection and data and information exchange among departments and companies allowed by a networked production" (Gherke *et al*., 2015). The vertical and horizontal integration is implemented by connecting the production systems with each other, so that there is a seamless data flow between all systems and even to the Internet (Simons *et al.,* 2017).

The introduction of the CPS and the IoT into the manufacturing industry, and the implementation of the horizontal and vertical integration help factories to adopt mass customization, increase the value of the products as a result of improvement in quality and flexibility, reduce lead time for prototype development, reduce delivery times and the inventory, achieve a better profitability due to reduction in labor cost and enhanced asset utilization rate which compensates for increase in automation-related depreciation (Roland Berger, 2015) and in general, be more competitive by improving their productivity and efficiency. But, in order to get those benefits of the Industry 4.0, new technologies have to be implemented in the different factories, and the labour force needs to be qualified enough to work with them.

Main technological changes

As mentioned before, the implementation of CPS will require the adoption of new technologies, tools, machines and methodologies. In order to understand which new technologies and methodologies will be needed in Industry 4.0, the 5Cs CPS structure presented in Lee *et al.* (2015) will be followed. This overview will lead to define a set of qualifications and skills of the workforce that will be necessary in the future manufacturing environment.

The CPS structure proposed in Lee *et al.* (2015) consists of five levels: Smart connection, Data-to-info conversion, Cyber, Cognition and Configuration. The Smart connection level consists of seamless and tether-free methods to manage data acquisitions systems and transfer them to the central server. Proper sensors, data sources and transferring protocols will be required due to their significant impact on the performance of the CPS in the next levels and the quality and accuracy of the knowledge. The Data-to-information conversion level is where value knowledge is obtained from the collected data. Intelligent algorithms and data mining techniques are essential in the transformation of the data into knowledge. In the Cyber level is where the cyber space is created to gather all the information from every source in order to extract additional information that provides better insight over the status of individual machines by using specific analytics. The created knowledge is monitored and represented in the Cognition level to support the decision-taking and control processes. The corrective and preventive decisions conform the feedback to the physical space to make machines self-configure and self-adaptive, this part corresponds to the Configuration level. Through the five mentioned levels, all the way from the data acquisition to the value creation have been followed.

Consequently, the Industry 4.0 will provide a new ecosystem. It involves the following features: smart machines, which will coordinate manufacturing processes by themselves; service robots that will collaborate with workers on assembly lines; smart transport systems that will transfer goods from one place to another (Roland Berger, 2015); tracking and identification systems (RFID, DMSs, etc.) which will allow to identify the product individually and each workstation will be able to perform exactly the task required for the actual order (Simons *et al.,* 2017); intelligent sensors to acquire the data and actuators to implement into the physical world the decisions taken in the cyber world (Gherke, *et a*l. 2015); and intelligent assistance systems with optimized human machines interfaces which will extract data and information from the different systems, e.g. MES, ERP, machines, sensors or PLCs (Prinz *et al*., 2017), to help the workers to make qualified decisions in a shorter time. All these features integrated with cutting-edge information technologies (Gherke *et al*., 2015). Such deployment of a large number of sensors and networked machines produce a continuous generation of high volumes of data, known as "Big Data", which have to be analyzed and managed through the cloud.

In addition, "all kinds of smart devices such as pads, wereables, or phones will provide the workers with the exact information they need in real time to perform their task efficiently" (Gherke *et al*., 2015). The junction of smart devices, and 2D and 3D virtual process simulations –"simulation of the production system using digital twins" (Simons *et a*l., 2017), will allow to perform production monitoring, remote control and diagnosis.

All of these advancements in the technological level will require qualified and high skilled workers in order to improve the productivity and the efficiency of the factory. In addition, it will change the organization and structure of the companies, the working environment and the way the intraorganizational and interorganizational cooperation is carried out. As a result, these factors will affect too the tasks and the required abilities of the labor force (Gehrke *et al*., 2015).

Future tasks and required skills

Windelband (2014) characterizes two scenarios regarding the role of people in Industry 4.0. In one scenario the IT systems are the ones who make decisions and control processes, limiting the men performance to manual labor. In the other scenario people use digital systems as an aid, in order to make profound decisions in a complex environment and then control processes using autonomously operating systems. In a similar way, Roland Berger (2015) mentioned two schools of thoughts that have emanated in expert discussion regarding the impact of Industry 4.0 on jobs. On the one hand, a number of experts believe that use of automation and robots in the shop floor associated with Industry 4.0 will act as a replacement for labor. On the other hand, some experts believe that Industry 4.0 technologies will result in an increase in employment because there will be a need for rising capacity in relation with the growth in the demand for quality products. There is no doubt that certain low-skilled jobs will be dismissed, although high skilled jobs will be created (Roland Berger, 2015).

Before going deeply in the definition of the tasks the humans will have to perform in the future industry, the skills and qualifications that will be needed and new educational training methods for actual and future workers, it is important to clarify that authors are in the school of thought that thinks new technologies will be used as an aid, and high skilled jobs will be created according to that. Indeed, human employees remain the decisive critical success factor (Schirner *et al*., 2013).

In accordance with Gehrke *et al*. (2015), the new tools, machines and technologies will affect the tasks the workers perform in a factory. Moreover, these new technologies will change the factories structure and organization, the working environment and the way they cooperate. The robots and smart machines will perform the monotonous, ergonomic and manual tasks, so the humans workforce will be release to perform more qualified work like control and supervision of processes (Gehrke *et al*., 2015). In order to perform that qualified and complex work, the labor force will have to work in teams and collaborate with other workers from others factories or decentralized control centers. Furthermore, it has to cooperate with other workers of the same factory through communication and information networks and in virtual worlds (Richert *et al*., 2016), with robots and machines, and with intelligent assistance systems which will compensate the lack of knowledge of the employees providing the exact data and information required (Prinz *et al*., 2017) and efficiently support the humans, the ones in charged to take the final decisions. In addition, the huge amount of data gathered from the smart machines and sensors will have to be managed by using intelligent algorithms, data mining techniques and Artificial Intelligence (A.I). These data and information must be stored in the cloud in a secure way.

Table 1. Qualifications and Skills of workers in a Factory of the future

	Must…	**Should…**	**Could…**
	… be included in the skillset of the skilled labor of the future		
Technical Q&S	IT knowledge and abilities	Knowledge Management	Computer programming/coding abilities
	Data and information processing and analytics	Interdisciplinary/generic knowledge about technologies and organizations	Specialized knowledge about technologies
	Statistical Knowledge	Specialized knowledge of manufacturing activities and processes	Awareness for ergonomics
	Organizational and processual understanding	Awareness for IT security and data protection	Understanding of legal affairs
	Ability to interact with modern interfaces (human-machine / human-robot)		
Personal Q&S	Self- and time management	Trust in new technologies	
	Adaptability and ability to change	Mindset for continuous improvement and lifelong learning	
	Team work abilities		
	Social skills		
	Communication skills		

Source: Gehrke *et al.* (2015)

Thus, the workers will have to develop competences like team working abilities, communication skills, knowledge about manufacturing processes, ability to interact with modern interfaces (human-machine/human-robot), IT knowledge and abilities, data and information processing and analytics skills and awareness for IT security and data protection, to name a few (Table 1) (Gehrke *et al*., 2015).

The aforementioned technological changes should and will proceed jointly with a significant change in organization and structure (Gehrke *et al*., 2015). The organization structure of the future manufacturing plants will become more flat, flexible, decentralized and changeable (Roland Berger, 2015). This is due to the fact that the introduction of new technologies will enrich all jobs of skilled labor with larger responsibility and more decision power (Gerhke *et al.,* 2015). Furthermore, the introduction of IT communication technologies that allows data and information flow, the use of smart devices and the interaction in virtual environments (Richert *et al*., 2016) will make obsolete to stand at one specific production station (Gehrke *et al*., 2015).

All of these changes in the technical level, the organization and structure, the working environment and in the way the cooperation and communication are carried out induce that being and expert or specialist on certain subjects become less important than the ability of global thinking, interdisciplinarity knowledge and an holistic understanding of organizations (Richert *et al*., 2016). Thus, "Industry 4.0 creates a need for many new cross-functional roles for which workers will need both information technology and production knowledge […] and this scenario would necessitate new formats for teaching and learning" (Sackey *et al*., 2017).

Towards new educational methods

The main qualifications and skills that are mediated in a classical technical apprenticeship of today, such as the "basic knowledge about material or metal processing, will remain in the core of the skilled labor education" (Gehrke *et al*., 2015). But, in the other side "an interdisciplinary understanding of systems, production processes, automation technology, information technology, ergonomic principles, knowledge of business processes and skills for cooperation and communication in interdisciplinary groups are of critical importance in the future manufacturing industry" (Simons *et a*l., 2017). Consequently, these new required skills have to be achieved in addition to the ones required in the present factories so that the employees and engineers have a holistic perspective on complex systems.

Unfortunately, the interdisciplinary and the holistic approach required by the Industry 4.0 scenario are not learned by classical lectures and internships (Faller *et al*., 2015). This means that universities and other education centers should change the way they implement teaching and learning methods. A way for doing that and for educating the future workers with the aforementioned required skills and qualifications is the problem-based or project-based learning in learning factories.

Problem-based learning is defined as a student-centered pedagogy, in which students work on real-world problems in relation with their working field (Simons *et al.,* 2017). The students shall "learn by doing", and the teacher should be a "guide-on-the-side" instead of being the center of the educational process. Problem-based learning emphasizes on multidisciplinarity, collaboration and group work (Harmer, 2014), skills with high importance in the future manufacturing scenario. "Project-based learning is based in the same features as problem-based learning but also focusing on project planning and project managing, as well on presentation and documentation" (Simons *et al*., 2017). Thus, these two learning methods have a great potential in developing the skills and qualifications required by the Industry 4.0 scenario. Specially, if they are implemented in the learning factories.

Learning factories are "learning environments in which participants are trained by the usage of simulated real production processes, which are as realistically and authentically as possible" (Abele *et al*., 2008). A learning factory offers learners the opportunity to implement process improvements and to see the results immediately. Its main aim is to bring the real world into the education environment by providing students with practical hands-on experience through real-life projects (Sackey *et al*., 2017). Other goal of a learning factory is effective competency developments in enabling users to master complex and unfamiliar situations (Abele *et al*., 2015).

In Abele *et al*. (2008), two main types of learning factories are identified, among others: physical learning factories which provide a real value chain for a physical product on-site (Sackely *et al*., 2017), and virtual learning factories which offer advantages of scalability, location independence and a widened scope of the problems to be addressed, but are less hands-on (Sackey *et al*., 2017).

So, learning factories have a huge potential in developing the skills of the workers, engineers and labor force of the future factories. But, in order to do that, "it is important that the learning factories have the same key features than an Industry 4.0 system: modularity of structure, for increased flexibility; interoperability, whereby entities communicate seamlessly with each other; virtualization, with a strong emphasis on simulation and decentralized decision-making; and real-time capability, for quick response and service orientation" (Sackley *et al.,* 2017).

The use of learning factories as a way for training and for educating the future workers of Industry 4.0 is not far from reality or an initiative to be implemented in the future. Nowadays real learning factories are already developed and they are being used for this purpose with excellent results. One example is the AutFab presented in Simons *et al*. (2017). The AutFab is a holistic fully automated Industry 4.0 learning factory. It covers most aspects of Industry 4.0 and was established by the faculty of Electrical Engineering and Information Technology and the faculty of Mathematics and Natural Sciences of the University of Applied Sciences Darmstadt. Problem-based and project-based learning methods are put into practice in the AutFab, in order to make the students acquire an interdisciplinary knowledge and collaboration. The students learn a wide variety of key technologies and methods for their later work. They claimed to be extremely motivated and "infected" by the fascination of the used technology. Other examples are the IoT laboratory "Application Center Industry 4.0" (ACI), which comprises a hybrid simulation environment combining the benefits of virtual and hardware simulation and components in order to design or analyze industrial manufacturing processes or value-adding networks (Gronau *et al*., 2017), and the Industry 4.0 Learning Factory invented at the campus Velbert/Heiligenhaus of the Bochum University of Applied Sciences, where the processes at the shop floor level are integrated to the top floor level and real-time supply chain information is provided, in order to enable a practice education of the students on the one hand and continues training professionals on the other (Faller *et al*., 2015).

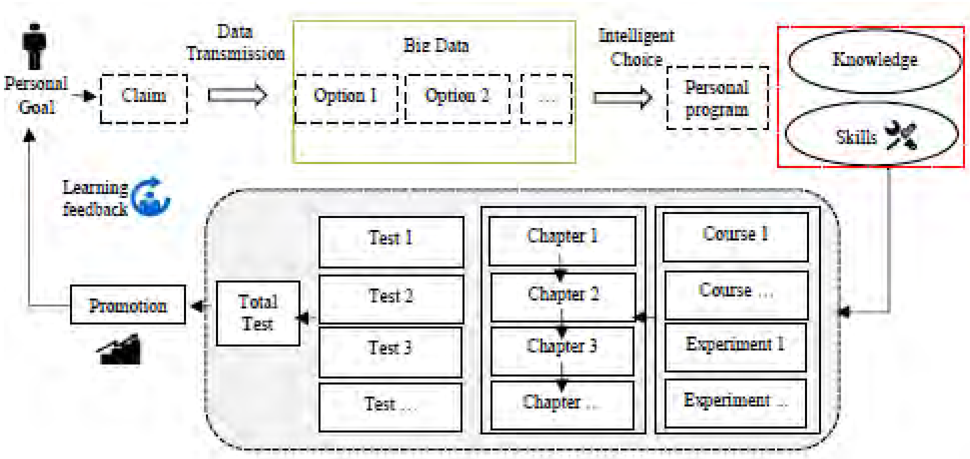
Therefore, is crucial that the universities and other education centers change their teaching and learning methods for preparing their students to their future working scenario in the manufacturing industry by applying problem-based and project-based learning methods in learning factories. But before, a didactic concept for a learning factory that specifies what is to be learnt, how it is to be learnt and by whom it will be learnt is required (Abele *et al*., 2015). In Sackely *et al*. (2017) an approach to a didactic concept and didactic design parameters for industrial engineering 4.0 learning factory is presented.

The need for a significant economic investment and the complex process of defining the learning objectives are two difficulties that the universities will face if they want to implement a learning factory. Therefore, it is important that universities, education and research centers collaborate together and with real-world industries. The real-world companies have to be involved in the educational process. Firstly, financial aid needs to be provided. Secondly, concrete skills definition must be established. In consequence, they will be benefited if most high-skilled students are educated. In ACI, within mutual trialogues between enterprise, employee representatives and learning factory representatives, content-related focuses, learning environments and teaching formats are carved out (Gornau *et al*., 2017). Thereby, requirements and suggestions can be identified which are not necessarily solely competence related, but also regarding enterprise processes changes (Gronau *et al*., 2017). In addition, if some universities do not have enough economic resources to implement a learning factory, they can work together and develop a virtual learning factory and gain benefits from the advantages it offers as location-independence. So, students from different universities will be able to work with the same virtual learning factory, share their experience, and acquire knowledge.

Another way for strengthening the education of competencies and qualifications which help to tackle the challenges of Industry 4.0, such as interdisciplinary collaboration and complex problem solving within changing and anonymous teams in virtual worlds, creative problem solving and hands-on experience, is the Virtual Learning Environments (VLEs) (Richert *et al.,* 2016). The technological advances that constitute Industry 4.0 induce that working in virtual environments with hybrid human-robots-teams spread all over the world become more and more common (Richert *et al*., 2016), because parts of the value chain will be operated and maintained fully remotely or on the basis of virtualized processes (Kagermann, 2013) and due to the higher degree of globalization. So, as it was mentioned before, these changes make that a different skillset is demanded, an a good way to deliver the proper educational settings is the VLEs. "The virtual environments will have a unique ability to alter the social dynamics of learning environments via transformed social interaction and they allow the students to train in a broad variety of domains for creative problem solving" (Richert *et al*., 2016). In addition, via VLEs the students can train in scenarios that would be impossible in the real-world due to danger or economic reasons (Richert *et al*., 2016).

Although the use of VLEs in higher education have increased in recent years, empirical analysis about the impact, advantages and disadvantages of the introduction of VLE into the learning processes are needed. Richert *et al*. (2016) conducted empirical studies about the adaptation and perspective of trainers within the virtual world and about the student´s behavior while collaborating in problem-solving processes in VLEs. They conclude that it have a huge potential in developing the Industry 4.0 required skills like problem solving within interdisciplinary teamworks, and that "trainers will have to be able to prepare VLEs as another teaching and learning tools" (Richert *et al*., 2016).

Figure 3. The Relationship of Promotion Process



Source: Wu *et al*. (2016)

Even though learning factories and VLEs should be used as methods to develop the future manufacturing workforce skills, maybe it is not enough. Wu *et al*. (2017) suggest that the change in the education must be wider, and new techniques as Artificial Intelligence, Big Data and network systems should be applied into the future education mode. Chinese education is shifting in that way (Lou, 2016). Wu *et al*. (2017) present that, due to the variety in the students interests and goals, capacities and learning abilities, a personalized education system is needed. A personalized education system can be achieved using new technologies, online learning platforms and intelligence guidance systems. So, the students will be provided with personalized education programs with specific courses and learning methods, material, reference books, teaching videos and experimental questions and contests through the network self-learning, such as cloud classroom, mobiles phones, distance learning and online learning. Then, they will receive feedback about their progress after a period of study and testing, and be recommended with next stages of the learning program in order to be promoted (Figure 2). With a personalized education system the personal learning efficiency will be maximized (Wu *et al.* , 2017). In the same way Industry 4.0 is inducing the manufacturing industries from mass production to mass customization, education must shift from mass education to customized education.

Conclusions

The new paradigm that Industry 4.0 represents and its associated technological and organizational changes induce that the education of future engineers and workforce needs to change jointly. New skills, competencies and qualifications such interdisciplinary knowledge and collaboration are required for achieving a successful implementation of Industry 4.0. In order to develop the needed skillset, problem-based and project-based learning methods in learning factories and the VLEs should be integrated into the educations systems due to its huge benefits and potential in training the workforce for the future manufacturing scenario. Nevertheless, education must change more drastically from the bottom by introducing new technologies and techniques, such as A.I, information networks and cloud computing, in order to provide the students with personalized education programs and thus maximize the efficiency of their learning process.

But before, is important to specify what it is to be learnt, how it is to be learnt and by whom it will be learnt, and in this process academic centers, governments and companies must work together. More research about new methods of training and education to prepare the students for their future working scenarios should be conducted, analyzing their potential benefits and barriers of implementation. But nowadays, it is evident that a life-long learning mindset and the ability to adapt to changes are crucial requirements for the future labor force.

References

Abele E., Eichhor, N. (2008). *Process Learning Factory- Training students and management for excellent production processes*. Advanced Manufacturing Systems and Technology. CISM, Udine, 63-73 pp.

Abele E., Metternich J., Tisch M., Chryssolouris G., Sihn W., ElMaraghy H., Hummel V., Ranz F. (2015). *Learning factories for research, education, and training*. Fifth Conference on Learning Factories, *Procedia CIRP*, 32, 1-6 pp.

Bagheri B., Yang S., Kao H., Lee J. (2015). *Cyber-Physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment*. IFAC-PapersOnLine, 48-3, 1622-1627 pp.

Bundesministerium für Bildung und Forschung / Federal Ministry of Education and Research (BMBF). *The new High-Tech Strategy, Innovations for Germany*. Berlin, 2013. On http: //www.hightech-strategie.de/de/The-new-High-Tech-Strategy-380.php. Last visited 4/12/2017.

Faller C., Feldmüller D. (2015). *Industry 4.0 Learning Factory for regional SMEs*. Procedia CIRP, 32, 88-91 pp.

Gehrke L., Kühn A.T, Rule D., Moore P., Bellman C., Siemens S., Dawood D., Lakshmi S., Kulik J., Standley M. (2015). *A Discussion of Qualificactions and Skills in the Factory of the Future: A German and American perpective*. VDI/ASME Industry 4.0 White Paper, 1-28 pp.

Gronau N., Ullrich A., Teichmann M. (2017). *Development of the Indsutrial IoT Competences in the Areas of Organisation, Process, and Intereaction based on the Learning Factory Concept*. Procedia Manufacturing 9, 254-261 pp.

Harmer N. (2014). *The benefits and challenges of project-based learning*. School of Geography, Earth and Environmental Sciences, Plymouth.

Kagermann H. (2013). *Recommendations for implementing the strategic initiative INDUSTRIE 4.0*. Acatech- National Academy of Science and Engineering, Frankfurt/Main, 2013.

Lee J., Bagheri B., Kao H. A. (2015). *A cyber-physical systems arquitectura for industry 4.0-based manufacturing systems*. Manufacturing Letters, 3, 18-23 pp.

Lee J., Ardakani H.D., Yang S., Bagheri B. (2015). *Industrial Big Data Analytics and Cyber-physical Systems for Future Maintenance & Service Innovation*. Procedia CIRP, 38, 3-7 pp.

Luo Y. (2016*). "Industry 4.0" is inseparable from "Education 4.0"*. People Education Newspaper (01).

Minerva R., Biru A., Rotondi D. (2015). *Towards a definiton of the Internet of Things (IoT)*. IEEE Internet Initiative, Torino, Italy.

Prinz C., Kreimer D., Kuhlenkötter B. (2017). *Implementation of a learning environment for a Industrie 4.0 assitance system to improve the overall equipment effectiveness*. Procedia Manufacturing, 9, 159-166 pp.

Richert A., Shehadeh M., Plumanns L., Groβ K., Schuster K., Jeschke S. (2016). *Educating Engineers for Industry 4.0: Virtual Worlds and Human-Robot-Teams*. IEEE Global Engineering Education Conference.

Roland Berger Consultancy (2016). *Skill Developmente for Industry 4.0*. BRICS India 2016.

Sackey S.M., Bester A., Adams D. (2017). *Industry 4.0 learning factory didactic design parameters for industrial engineering education in South Africa*. South African Journal of Industrial Engineering, 28, 114-124 pp.

Schirner G., Erdogmus D., Chowdhury K., Padir T. (2013). *The future of human-in-the-loop cyber-physical systems*. Computer, 46(1), 36-45 pp.

Simons S., Abé P., Neser S. (2017). *Learning in the AutFab – the fully automated Industrie 4.0 learning factory pf the University of Applied Sciences Darmstadt*. Procedia Manufacturing, 9, 81-88 pp.

Wang S., Wan J., Li D., Zhang C. (2015). *Implementing Smart Factory of Industrie 4.0: An Outlook*. International Journal of Distributed Sensor Networks, 2016, 3159805.

Windelband L. (2014). *Industrie 4.0 – Die nächste industrielle Revoluation? Konsequenzen die berufliche Bildung*. 6. Engineering- und IT-Tagung, Rüsselheim.

Wu G., Sun X. (2017). *From the Industry 4.0 to Intelligent Personalized Education Model*. International Conference on Modern Education and Information Technology (MEIT), ISBN: 978-1-60595-468-4.