Human Capital 4.0: a workforce competence typology for Industry 4.0

Emmanuel Flores, Xun Xu and Yuqian Lu
The University of Auckland, Auckland, New Zealand

Received 26 August 2019
Revised 1 November 2019
Accepted 9 December 2019

Abstract

Purpose – The purpose of this paper is twofold: to raise and address an important change for the human capital in the future of Industry 4.0, and to propose a human-focused perspective for companies underneath the new Industrial Revolution.

Design/methodology/approach – The research study follows a state-of-the-art literature review process. The nature of the selected approach enables to cover the extensive aim of the paper with sufficient scientific solidity that should support the understanding of every topic.

Findings – This work has presented three relevant aspects for Industry 4.0 and its human labour force: a workforce architecture with new interactions, a term to embrace the human capital of the future and a typology for referencing the required competences for Industry 4.0.

Research limitations/implications – The paper sheds light on an important aspect for the emerging Industrial Revolution, the human force. The result and conclusion sections suggest future implications for academia and the private sector, due to changes at the conceptual and practical levels of human operation in the industry – for example, new structural interactions among employees, additional qualities to human capital and different ways to identify the competences for the workforce.

Originality/value – This is an interdisciplinary study that tries to bring together a modern industrial term, a social focus and a company scenario. From this, it was possible to obtain a new social term, a novel typology of competences and a new company-scenario interaction.

Keywords Human capital 4.0, Competences and skills, Typology, Workforce architecture, Industry 4.0-enabled interaction, Industry 4.0

Paper type Research paper

1. Introduction and motivation

The new paradigm of Industry 4.0 is rapidly spreading worldwide. This revolutionary concept offers the story of the next Industrial Revolution as a flexible platform where technologies and the Internet are pervasive means to do businesses and manufacturing.

Efforts have been made to propose future tendencies and shifts in terms of technologies, systems and tools. However, there still seems to be a lack of considerations for future workers, especially at a holistic view. In other words, there is a need for a corresponding term and scenario for humans in parallel to Industry 4.0. To address this need, the following questions demand an answer:

RQ1. How does the future interaction and communication look like for employees in a manufacturing company? What type of new structure and activities may arise from such new interactions?

RQ2. What is the best term to represent an inclusive set of future-proofing attributes of the workforce?

RQ3. What are the competences required for this new paradigm shift?

The research reported in this paper attempts to answer these questions by having carried out a state-of-the-art review. This methodology allows both to address a wide literature and topic, and to highlight perspectives for further research (Grant and Booth, 2009), which resonates with the aim of this paper.

Journal of Manufacturing Technology Management
Vol. 31 No. 4, 2020
pp. 687-703

1741-038X
DOI 10.1108/JMTM-08-2019-0309

In this sense, the work presented elaborates on the new changes at the factory atmosphere, such as its architecture levels and the workforce interactions. Furthermore, it also proposes a new approach and term with a human-focused perspective in order to meet the challenges of the future labour force. This new term is "Human Capital 4.0". This is a holistic approach of the human force worth considering for different aspects required for a successful adoption of Industry 4.0. Lastly, we present a novel competence model to enhance the understanding and application of every type of skill.

The remainder of the paper is organised as follows. Section 2 presents state-of-the-art literature on existing terminologies within Industry 4.0, the factory structure, the workforce architecture and interactions and the review of human capital and competences. Section 3 provides the results and discussion to the three initial questions to be answered. Section 4 gives conclusion and further implications of the results. Section 5 mentions the limitations of the research and future work.

2. Literature review

2.1 Industry 4.0 and recent terms

Industry 4.0, also known as the 4th Industrial Revolution, is the new shift paradigm that embraces latest technologies to boost industrialisation at local and global scales. Industry 4.0 enables a whole network of interconnected, dynamic, collaborative, reconfigurable, self-organised and personalised business services and manufacturing interactions (Zhong *et al.*, 2017), (Liu and Xu, 2016). It is important to heed that these interactions are applicable to the different models of how providers and users create a business ecosystem. This would mean that most, if not all, companies of different sectors will see themselves impacted to a varying extend under the vision of Industry 4.0.

The manufacturing sector, as one of the top financial drivers (Baena *et al.*, 2017; Qin *et al.*, 2016), is putting vast amount of effort to the adoption and implementation of Industry 4.0. This effort has led to numerous research outputs in the form of both technological and human-focused approaches.

An example of this is the cyber-physical production systems (CPPS), which are systems with collaborative and autonomous components that are connected to each other at the different levels of production and logistic processes (Monostori, 2014). Machine Tool 4.0, which is regarded as the self-aware, self-maintained and self-optimised smart machine tool, can provide assessment of its current and predictive used condition (Xu, 2017). Cyber-physical machine tool (CPMT) is proposed as a CPS application that integrates tooling, processing, networking and embedded computing to monitor and control machining process (Liu *et al.*, 2017).

Other researchers have implicitly commented on the cooperation of technical and human approaches together. CPSS (Smirnov *et al.*, 2014) and human-cyber-physical systems (HCPS) (Seshia *et al.*, 2015) are two of the examples that stress the integration and interaction among the physical, digital and human world. Moreover, the evolution of past, present and future of intelligent HCPS has been explained, and it is expected that future systems will strengthen industry and human society by leading the path to an "age of intelligence" (Zhou *et al.*, 2018).

Lastly, two recent examples of Industry 4.0 social concepts are Operator 4.0 and Education 4.0. The former is referred to the shop-floor worker in the smart manufacturing company of the future, and is regarded as being the skilful and clever worker supported by integrative systems to aid his/her sensorial and physical capabilities (Romero *et al.*, 2016). Education 4.0 is the proposed education that is characterised by the support of artificial intelligence (AI) in the learning process (Ciolacu *et al.*, 2018). It aims to cover six facets of the future of education: new learning formats, location and time independence, individualised learning, globalisation, skill sharing and lifelong learning.

2.2 Factory architecture
The well-known pyramid structure of modern production systems (Rojko, 2017) makes possible to visualise and allocate the different levels of management and operation at a given company. This structure represents the common existing architectural hierarchy in most companies. However, the new vision and aim of Industry 4.0 is reshaping the structure towards a flexible, self-organised and decentralised communication among all levels of the company (Ochs and Riemann, 2017). This new organisation style can also be called organic organisation design, for its feature of being adaptive, looser and free-flowing (Daft, 2015).

Figure 1 depicts the expected transformation of the traditional factory architecture into the new emerging structure for Industry 4.0 factories:

Pyramid (a) represents the conventional structure of levels of operation in a company: Enterprise resource planning (ERP), manufacturing execution system (MES), process control level, machine-device level and the finished product (Rojko, 2017).

Pyramid (b) gives some examples of the different elements that can be involved in each level. For instance, the enterprise top level may include human resources and management offices. The MES level may incorporate production planning and warehousing facilities from which production can be planned and supported. The third level can involve laboratories and workstations that can aid on the supervisory control of the production process. The shop-floor level may include machines, robots, PLCs and so forth. Lastly, finished goods already in the market tend to be out of the reach of the manufacturing company.

Image (c) alludes to the emerging structure that is expected in Industry 4.0. The centralised and hierarchy-based organisation and communication are replaced with a web or network, where all the elements in each level can communicate and cooperate with one another indistinctively. In addition, there will be the capability of integration with the finished products at the market (at customers' hands), becoming smart products (Almada-Lobo, 2016).

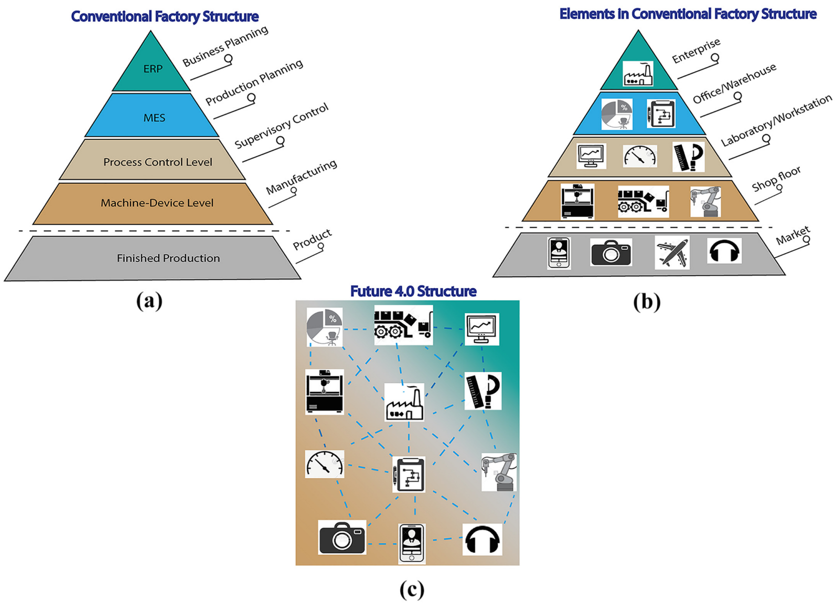

Figure 1.
Transition from traditional factory architecture to Industry 4.0 structure

2.3 Workforce interactions, activities and architecture

Industry 4.0 is imposing a paradigm-shift towards organisation structures and human roles and activities. Due to this change, the role of human factors needs to be placed in the centre as they are considered the leading component for a given revolutionary shift (Plonka, 1997).

The attempt of Industry 4.0 for achieving personalisation of products and services (Wan *et al.*, 2015) will require reconfiguration of on-demand production systems (Hu, 2013), adoption of flexible, adaptable and efficient manufacturing networks and the integration and communication between producers and customers (Li *et al.*, 2017). Moreover, as future smart factories will be empowered by the Internet of Things (IoT) services (Shariatzadeh *et al.*, 2016), it can be suggested that IoT would also allow pervasive computing connection among people, creating the Internet of People (IoP) (Miranda *et al.*, 2015). All of these together will make changes at the communication structure of companies. In addition, customers now will become part of the exchange of information in the manufacturing process (Rüßmann *et al.*, 2015), making them part of the new network.

Industry 4.0 will not only change the workforce interactions, but also will have an impact on the activities that individuals undertake, as they will need to become more coordinated, creative and strategic. A literature review on this topic has envisioned possible changes (Bonekamp and Sure, 2015). First, the operational working level will be highly aided by cyber-physical systems. Second, a higher decentralisation in decision-making and planning processes will be achieved. Third, ongoing process integration and cross-functional perspectives will become the norm. Fourth, quality and maintenance will become automated, increasing the complexity and dexterity to integrate and manage them. Last, the working life and partner networks will gain more flexibility and importance.

Another study integrated new possible changes of work activities into four different perspectives: technical, methodological, social and personal (Hecklau *et al.*, 2016). A growing digitalisation, a daily utilisation of servers and a higher complexity integration of systems are considered within the new technical activities. A higher service-orientation and customer relationship, an examination of large amounts of data, a continuous sourcing of information and a higher process responsibility will be part of new methodical tasks. Social activities will comprehend an increasing level of virtual communication, a highly globalised networking, an explicit expertise and knowledge exchange and a flattening of hierarchies while adopting more responsibilities. The personal activities will embrace an increasing work-task allocation independent of time and place, a frequent work-related change and challenges, a continuous involvement with innovation and sustainable initiatives and a stricter policy application on digital security.

As per the architecture of the workforce, there are five main components in a manufacturing organisation (Goffee and Scase, 2015). The first component is the strategic apex, which is the responsible entity for formulating and implementing strategies in an organisation, that is, the plant manager. The next component is the middle line, who is represented by a hierarchy model that links and keeps the information flow (up and down) between the strategic apex and the operating core, that is, the operations manager. The third component, operating core, represents operators who do the basic work, producing goods and providing services (i.e. securing inputs and distributing materials). There is also the techno-structure component, who is the analyst that provides service to the production process by studying and planning work, that is, a project engineer. Lastly, the support staff, who provide in-house assistance and support to the different areas of an organisation, that is, the payroll administrator in human resources.

2.4 Human capital and workforce competence

The traditional term of human capital has been compared similarly to the physical assets of a company. However, in this case, the assets are the skills, health, education and expertise of the workforce (Goldin, 2016). This inventory of attributes or assets infers the well-being and productivity of an individual within a work environment.

Considerable emphasis is given in the literature from different organisations, governments and institutions worldwide about the skills required to embark on and cope with the future of industry. A big reason for this might be that economic growth, productivity and employability are often researched and associated to the increasing upskilling of individuals (Chryssolouris *et al.*, 2013). A competence is the combination of attributes, abilities, skills, knowledge and experience from a person, which are necessary for performing life and job roles (Meyer *et al.*, 2015).

Three recent studies have been conducted to bring up the topic of competence requirements and models for current and future work (Hecklau *et al.*, 2016; Meyer *et al.*, 2015; Hecklau *et al.*, 2017). However, they keep a very holistic viewpoint of the presented models, that is, lacking further information on how the categories in such models affect the workforce in the Industry 4.0 context. Moreover, the approaches in those studies only mentioned generalised categories, missing the emerging separation of important competences nowadays, such as the digital skills and emotional intelligence. Both types of competence have been proved to influence work performance (Miao *et al.*, 2017; Eshet-Alkalai, 2004). The omission of deeper knowledge and attributes among the competences could make more difficult the assessment and training of skills for workers.

Soft skills are linked to traits and personality types, and their initial studies began in the middle of the 19th century (Heckman and Kautz, 2012). Soft abilities are the compilation of traits that reflect social graces from a person in a given environment (Haeffner and Panuwatwanich, 2017). Another given term for these popular skills are social traits or non-cognitive skills (URCIUOLI, 2008). These types of abilities are of high importance because they allow individuals to manage the interaction with others (Laker and Powell, 2011) by becoming more adaptable, interdisciplinary and open to continuous learning (Sackey and Bester, 2016). Value of this competence cluster lies mainly on a self-monitoring performance (Robles, 2012). For example, teamwork, a particular skill in this classification, is highly preferred by companies dealing with rapid changes, high customisation and R&D involving suppliers and customers (Bikfalvi, 2011). However, an existing view of these types of abilities shares opinion about students, job applicants and employees lacking soft competences (Mitchell *et al.*, 2010).

Hard skills are referred as the specialised knowledge for a given occupation, and which boomed during the Henry Ford's era (URCIUOLI, 2008). They are also known as technical skills (Cotet *et al.*, 2017), which are the abilities and knowledge required for performing a trade, craft or job, which requires special dexterity, training or experience (Robles, 2012). These skills tend to be the most frequently trained skills in companies due to a more restricted and constant environment. Although these skills have been seen more often as hands-on work (i.e. with equipment or hardware), they are not limited to that alone. As long as they serve the purpose of an occupation or job role, they can fall in this typology. Some examples are working with data, software or even with abstract know-how or knowledge, like methodical techniques. However, these skills alone are not considered sufficient for job success (Laker and Powell, 2011).

Cognitive skills are understood as the intellectual abilities that allow learning. Studies in the 1980s and 1990s have validated the impact of these on job performance, training and achievement for general areas in life (Schmidt, 2002). Cognitive skill is the ability to learn as it supports the mastery, dexterity and performance of a particular subject or task (Hunter, 1986). Intelligent quotient (IQ) is the other common term for this competence (Kautz *et al.*, 2014). Studies and models have been developed to show and point out the relation between economic growth and the level of cognitive skills (Hanushek and Woessmann, 2008, 2012), where individuals and countries with greater cognitive skills achieve better financial growth. Furthermore, it is also believed that considering cognitive attributes in the development of new technological systems will lead to better task accomplishment (Nathanael *et al.*, 2016).

Emotional skills are referred as the drive or self-state that directs behaviour, and this concept and its studies began in 1990 (Berrocal and Pacheco, 2006). Emotional intelligence (EI), or emotional quotient (EQ), is the capacity to perceive, understand and regulate emotions in oneself to lead thinking and actions (Peter, 2010). Studies agree on this competence to have a strong influence and contribution towards satisfaction, commitment, motivation, performance, stress and quality decision-making of employees, because it supports in complex control activities (Miao *et al.*, 2017). Moreover, individuals with high EQ are expected to achieve easier success at their commitments, whether personal or professional, due to better ability to handle new challenges and resilience to frustration and stress (Rezvani *et al.*, 2016).

Digital skills are the dexterous abilities for understanding and using digital content, devices and systems to perform activities. Popularity of these skills is thought that to have begun in mid-1990s (van Dijk, 2006). Digital skills refer to the abilities that enable individuals to operate digital media (i.e. computers, devices, networks) and to search, process and apply data in such digital media (Van Dijk and Hacker, 2003). Nevertheless, these skills also involve a variety of other competences, namely, cognitive, social or technical, to perform activities in the digital world (Eshet-Alkalai, 2004). Digital abilities support interaction and communication in three different contexts: the personal, social and professional. The personal context is believed to be a basic level, the social context is considered an intermediate level and the professional context is seen as the advanced level (UK, 2016). In addition, a framework has been created to support the applicability and understanding of these abilities. The framework addresses five competent areas to develop digital skills (Vuorikari *et al.*, 2016), see Table 1. The framework gives a very inclusive viewpoint, covering any given digital skill or activity in mainly five areas and two dimensions.

Dimension 1	Dimension 2
1. Information and data literacy	1. Browsing, searching and filtering data 2. Evaluating data, info and digital content 3. Managing data, info and digital content
2. Communication and collaboration	1. Interacting, sharing and collaborating through digital technologies 2. Engaging in citizenship through digital technologies 3. Netiquette 4. Managing digital identity
3. Digital content creation	1. Developing digital content 2. Integrating and re-elaborating digital content 3. Copyright and licenses 4. Programming
4. Safety and security	1. Protecting devices 2. Protecting personal data and privacy 3. Protecting health and well-being 4. Protecting the environment
5. Problem solving	1. Solving technical problems 2. Identifying needs and technological responses 3. Creatively using digital technologies 4. Identifying digital competence gaps

Source(s): Adapted from Vuorikari *et al.* (2016)

Table 1.
Framework DigComp 2.0 for five areas of digital skills

3. Results and discussion

In this section, we have addressed and presented an answer to the research questions pointed out in the Introduction section. In addition, there is some discussion around their practical implications.

3.1 Q1, how does the future interaction and communication look like for employees in a manufacturing company? What types of new structure and activities may arise from such new interactions?

As described above in the literature, factories' architecture is likely to change and adapt in the future of industry. Therefore, a change in the interaction and communication among workforce can also be implied. Figure 1 helped as a support to picture existing elements in a factory, but also it can help to picture possible existing human job roles at different levels. In this sense, it is possible to appreciate a wider perspective of the whole workforce and possible interactions within the factory.

Figure 2 displays an envisaged change from a present pyramid-based communication channel, towards the new communication flow. This is a communication network aimed for Industry 4.0, which can also be called heterogeneous social network (Zhang *et al.*, 2015). The pyramid represents a typical hierarchy interaction among people working in a factory, where management and instructions are centralised, passing from high to lower levels, and vice versa. On the other hand, the network image mimics what could be the expected change emerging from Industry 4.0, breaking down the need for centralisation and opening for flexibility. The workforce will become a human labour network, where every node represents a member of the company, and every dashed line is an interaction and communication channel between them.

Consequently, Figure 3 helps to illustrate the workforce communication structure towards Industry 4.0 in a manufacturing organisation. The figure considers the examples of the five main components in a company given and described above in the literature (plant manager, operation manager, machine operator, project engineer, payroll administrator). They all will be highly enhanced by the utilisation of nine Industry 4.0 technologies (Rüßmann *et al.*, 2015). At the same time, they will be operating influenced by the alignment towards eight Industry 4.0 promising goals (Kagermann *et al.*, 2013).

Some practical benefits of having such interactions in the new Industry4.0-enabled communication are to be able to achieve flexibility, openness and accountability for

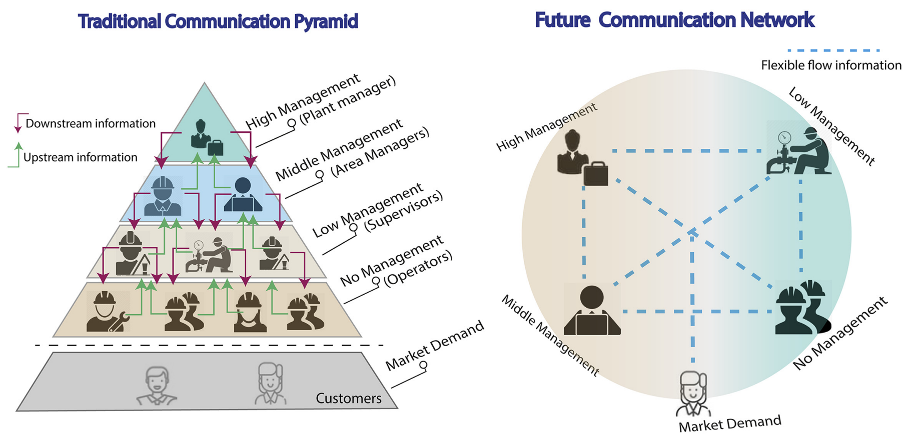

Figure 2.
Shift from traditional communication architecture to future communication network

knowledge and input of every member. Another benefit is that they promote a decentralised approach by opening opportunity to contact and interact with all members in the network mesh in a boundless way – not being subjected to centralised or stocked information. This type of quick-adapted interaction will also enhance changes in the company and in manufacturing processes by allowing last-minute notifications and modifications. All of these beneficial capabilities will offer a supportive role position for the workforce. Therefore, in return, it will also deliver opportunities for an increasing motivation, responsibility, coordination, creativity and lifelong learning of workers.

From the depicted illustration in Figure 3, a list of foreseen activities enhanced by instant digital interactions among the organisation can be discussed:

(1) The plant manager system will be able to check the performance of every member, assessing outcomes and opening individual digital channels of communication (if required) to achieve goals and strategies of the company.

(2) The operations manager will use the digital platform to support both the new production-line runs with the project engineer, and the creation of summary reports of personnel assistance with the payroll administrator. In addition, she/he will follow-up production-line issues with the machine operator, and elaborate production department budgeting with the plant manager.

(3) The machine operator communication channel will allow connections with every member. For example, with the plant manager for providing feedback on the job environment, with the operations manager for feeding information about production process status, with the project engineer for stressing quality issues with products and with the payroll administrator for reporting a self-health condition to be considered.

(4) The digital server of the project engineer will communicate with the plant manager for updating on new product releases and expected lead-times. Interaction with the operations manager will allow performance monitoring of new production lines. Direct contact with the machine operator will make it easier to follow-up on status of

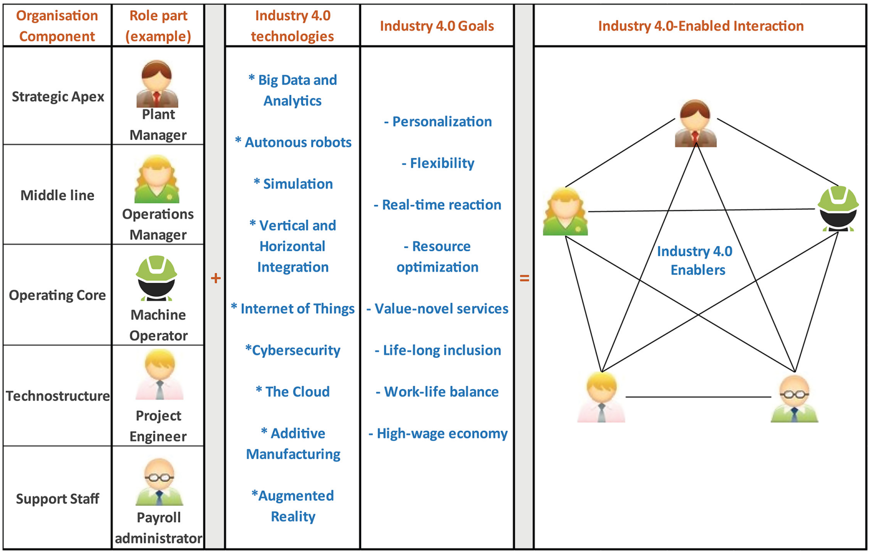

Figure 3.
Basic Industry 4.0-enabled interaction in a manufacturing industry

new manufacturing products. Interaction with the payroll administrator will enable to keep track and easy access to the personal archives.

(5) The digital platform of the payroll-administrator will allow interaction with the plant manager for quick approval of the payroll list. Meanwhile, the connection with the operations manager will support the prompt approval of working hours and bonuses from workers. The communication with the machine operator will enhance clarity when abnormal circumstances need clarification, that is, unjustified absences, bonuses or working hours. The connection with the project engineer will enhance filling in and updating the matrix of working competences from trainings delivered to the personnel.

3.2 Q2, What is the best term to represent an inclusive set of future-proofing attributes of the workforce?

There is a need for a term that can enclose those attributes of the Industry 4.0 vision. Moreover, the updated or new term should include the innovation perspective of Industry 4.0, since it is aiming for the transformation towards new innovative business models and novel economy (Morrar and Arman, 2017). This means labour force will also need to exhibit some extent of creative, resourceful and interdisciplinary knowledge in order to foster the novel side of Industry 4.0.

Furthermore, the Working Group, in their report called "Recommendations for implementing the strategic initiative Industrie 4.0" (Kagermann *et al.*, 2013), has acknowledged and pointed out the relevance of future employees' well-being as a means for higher productivity and dynamics. Therefore, well-being should also be included in the new term as something more comprehensive than that of health. The concept of well-being is defined as the equilibrium between the set of resources and challenges in different aspects, such as psychological, social and physical (Dodge *et al.*, 2012).

In this sense, the term Human Capital 4.0 proposed in this research appeals for the future-proofing set of competences, education, well-being and innovation that may support the workforce to cope with the Industry 4.0 paradigm. Recognition and consideration of these four main aspects from the human capital should promote those benefits and changes sought by Industry 4.0, see Figure 4.

3.3 Q3, What are the competences required for this new paradigm shift?

In this section, we have aimed to present and cover the workforce competences as a whole, with a particular set of comprehensive and inclusive competences to ponder in the vision of

Figure 4.
Main components from Human Capital for Industry 4.0

Industry 4.0. This model aims to support a better interpretation and application of future competences by:

(1) Exploring on how each competence might support Industry 4.0 endeavours

(2) Giving pool examples of the most sought skills that the literature and companies agreed on

(3) Dividing the competences into five singular categories to make easier the classification and assessment level of each competence and/or skill

(4) Explaining similarities or differences among each category when applicable, that is, a professional or technical skill from a digital or IT skill

(5) Using industrial and social common terms found in the literature to name and allude to the typology of competences for its easier understanding

3.3.1 A typology-competence set for Human Capital 4.0. Similarly to Industry 4.0, which gathered existing enabling technologies for its conception in 2013, the following typology brings together five main existing competences for Human Capital 4.0. See Figure 5 for the enabling competences.

The suggested typology already covers and allocates the 14 most wanted skills resulted from a recent meta-study analysis of future competences in Industry 4.0 that included the results of 2079 enterprises surveys and 150 experts' interviews (Hecklau *et al.*, 2017). Nevertheless, further skills have been also allocated as examples of the most wanted skills for each type of competence.

3.3.1.1 The soft workforce competence: flexible and social. As Industry 4.0 is making its disruptive way through industries, soft skills are playing a key role for future jobs. They will exhibit the opportunity for social responsibilities, such as quick adaptation or cooperation, which can lead to successful or negative outcomes. These abilities will enable the interconnectivity, self-adaptability and decentralisation of job positions sought by Industry 4.0 at the human capital level. One clear need of this competence is that multicultural collaboration dexterity has been seen relevant in future intercultural organisation networks (Weilkiens, 2015).

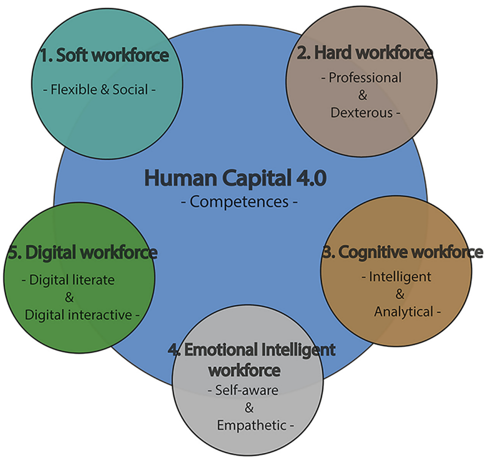

Figure 5.
Five enabling competences required for Human Capital in Industry 4.0

The soft workforce, who is flexible and social, alludes to the most common wanted pool of soft skills for the future. These skills are communication, teamwork or cooperation, leadership, willingness to learn, self-development, negotiation and flexibility or adaptability (Hecklau *et al.*, 2017; Motyl *et al.*, 2017; Piñol *et al.*, 2017; Robles, 2012; Schulz, 2008).

3.3.1.2 The hard workforce competence: professional and dexterous. Jobs in Industry 4.0 will be hugely impacted by this typology as many disciplines are merging. It should not be surprising that many of the new hard skills can be classified within the digital competence category as well. For instance, "programming" can be both a technical and a digital skill, but "surfing the network" can be only a digital skill without necessarily being a technical skill required for a job. Furthermore, in the case of "programming", and other similar "digital-hard" skills, it would be safe to assume that this admixture among types of competence comes from the interdisciplinary approach of a physical and digital world needed for Industry 4.0.

The hard workforce, who is professional and dexterous, should cope with the next pool of most discussed technical skills of future jobs. The pool covers industrial organisation, industrial processes, standards understanding, problem-solving techniques, designing with software, human-machine interactions, digital network settings, digital security and coding or programming (Hecklau *et al.*, 2017; Motyl *et al.*, 2017; Mourtzis, 2018; Pinzone *et al.*, 2017).

3.3.1.3 The cognitive workforce competence: intelligent and analytical. The importance of cognitive skills increases with the complexity level of tasks or systems (Heckman and Kautz, 2012). Therefore, future jobs in Industry 4.0 will be impacted by this classification since the integration of new concepts and technologies is brewing complex, interconnected networks and systems. Human labour will have to learn how to use and interact with new software (i.e. systems, platforms, cloud) and new hardware (i.e. equipment, machines, mobile devices) that will be built to incorporate the digital integration. Although technological efforts are developed to support the human adoption to new systems, still humans will need to keep learning. It will be required to keep developing cognitive skills in the workforce because they support the self-autonomy in workers, which is another aim for Industry 4.0.

The skills of the cognitive workforce, who is intelligent and analytical, are divided in three aspects: aspect one, verbal aptitude (i.e. vocabulary, spelling, and reading), aspect two, numerical aptitude (i.e. math, arithmetic) and aspect three, spatial aptitude (i.e. coordination, memory, decision-making, problem-solving thinking, abstract reasoning, analytical thinking) (Alloway *et al.*, 2004; Farkas, 2003; Hecklau *et al.*, 2017).

3.3.1.4 The emotional intelligent workforce competence: self-aware and empathetic. Addressing the importance of this competence for new roles should smooth the transition of exiting business models into new Industry 4.0 models. Emotional intelligence may provide future jobs with answers to stress, fatigue and the working-life balance that Industry 4.0 aims to achieve. In addition, since EI is linked to influence the drive and motivations in employees, considering and leveraging this skill can potentially support existing challenges. For example, the demographic concern of the ageing population could find an answer by lifting the spirit of senior employees and persuading them to stay longer in their career paths. Moreover, this competence might be a tool to tackle the workload and anxiety sensation that has been reported to come from human-robot collaboration practitioners (Koppenborg *et al.*, 2017).

The skills that have been identified for the emotional intelligent workforce, who is self-aware and empathetic, are self-awareness, self-control, positive outlook, empathy, achievement orientation and motivation (Boyatzis *et al.*, 2017).

3.3.1.5 The digital workforce competence: digital literate and digital interactive. The impact of digital skills is absolute for Industry 4.0 jobs. The elements of the digital world make the bloodstream for the whole idea of Industry 4.0 itself. Therefore, the learning and mastery of these abilities could not be an option for the future of human labour. It may be safe to say that this new digital era is here to stay. Therefore, the workforce will be compelled to adopt these skills.

The pool of most common skills wanted for the digital workforce, who is digitally literate and interactive, tends to be among those in the professional level. The list includes programming, cybersecurity, digital networks, cloud computing, databases, web development and also the management of Industry 4.0 technologies (i.e. IoT, big data analytics, 3D printing, simulation, augmented and virtual reality) (Hecklau *et al.*, 2017; Piñol *et al.*, 2017; Pinzone *et al.*, 2017; Sackey and Bester, 2016; Zhang, 2012).

It should be noted that most of these digital skills, as also being skills required to perform a job role, could also fit under the hard/technical competence classification.

4. Conclusion and further implications

This paper has shed some light in three relevant aspects of industry and its human labour force: a workforce architecture with new interactions, a term to embrace the human capital of the future and a typology for referencing the required competences for Industry 4.0.

The architecture and workforce communications will find themselves impacted by the connectivity and interoperability sought in Industry 4.0. Moreover, the self-adaptability and decentralisation in the systems are also believed to affect the existing model of interaction among co-workers in manufacturing plants. A new Industry4.0-enabled interaction is proposed, where elements of the company will be interactively enhanced and influenced by Industry 4.0 technologies and goals. Examples of emerging activities have been also given. Although the literature mentions different ways of new connections and interactions in general, further research needs to be done considering more realistic manufacturing scenarios with the workforce elements as a whole. Whether this emerging interaction model will influence the existing hierarchical or authoritative ladder in a company is also a question worth pondering. In addition, a focus for research should be whether existing technological settings already offer opportunity to smoothly display the future architecture among the manufacturing workforce.

With Industry 4.0 posing disruptive challenges at different scales (i.e. business models, manufacturing processes, economy), it is necessary to upgrade the human force at different levels (i.e. technical, psychological, social) to meet those changes. Therefore, Human Capital 4.0 is proposed as a holistic shift in terms of competences, education, well-being and innovation that the workforce should exhibit for the era of Industry 4.0. Future workforce will need to be highly adaptable, resourceful, resilient and interdisciplinary for interaction and collaboration in the industrial market. It is not claimed that the new concept proposed covers all the variety for possible unforeseen needs in the new industry. Instead, it is expected that this term serves as a platform for continued discussions.

Lastly, a novel typology of competences for human capital of the future was developed. The soft workforce will exhibit the interconnectivity and self-adaptability in the company through flexible and social interactions. The hard workforce will demonstrate enhanced knowledge of basic work, that is, industrial processes or working techniques, but also will adopt high-level digitalisation expertise. The cognitive workforce will show self-autonomy and management of complexity through increasing learning and experience. The emotional intelligent workforce will undergo change adaptations through proper motivation and perspective development. The digital workforce will do and perform all types of work activities in a digital-context scenario through the understanding and utilisation of digital means.

The proposed typology not only covers why these qualities are required for Industry 4.0, but also attempts to emphasise the particularity and difference among them. In this way, it should be easier to improve methods and tools to train and assess such qualities, respectively. This is another area that can be benefitted from further research.

Today, in the 21st century, it should work as an opportunity to heed that disruptive technological changes should be undertaken for the benefit of humans and the planet. The Industry 4.0 paradigm proposes a shift in thinking and actions from the traditional way. Such changes will have a high impact on human labour. Therefore, continuous work needs to be done at holistic perspectives in order to support the transition from a conventional to a new thinking and operational model.

Industry 4.0, as well as its previous precursors, came out of technological disruptions, requiring a post adaptation from humans. Perhaps one day, fully developed competences of humans could come before and be the trigger for the next disruptive Industrial Revolution in line.

5. Limitations and future work

As stated above, this paper was based on a state-of-the-art literature. Although this helps us to offer a wide picture of the topic with relative fresh information, it does not lend itself for delving further into each section. Therefore, the limitations of this article are framed within the nature of it by not digging deeper into every subtopic. Furthermore, another factor or term left out in this research, which may be suitable to consider, is sustainability and its role within human capital.

Future work aims to propose an assessment test of the Human Capital 4.0 competence typology in a physical and/or virtual prototype setting that can be displayed in a laboratory. In addition, foreseen work considers the development of a novel model for training and education of workforce.

References

Alloway, T.P., Gathercole, S.E., Willis, C. and Adams, A.M. (2004), "A structural analysis of working memory and related cognitive skills in young children", *Journal of Experimental Child Psychology*, Vol. 87 No. 2, pp. 85-106, doi: 10.1016/j.jecp.2003.10.002.

Almada-Lobo, F. (2016), "The industry 4.0 revolution and the future of manufacturing execution systems (MES)", *Journal of Innovation Management*, pp. 16-21, available at: https://journals.fe.up.pt/index.php/IJMAI/article/view/2183-0606_006.001_0005/324.

Baena, F., Guarin, A., Mora, J., Sauza, J. and Retat, S. (2017), "Learning factory: the path to industry 4.0", *Procedia Manufacturing*, Vol. 9, pp. 73-80, doi: 10.1016/j.promfg.2017.04.022.

Berrocal, P. and Pacheco, N. (2006), "Emotional intelligence: a theoretical and empirical review of its first 15 years of history", *Psicothema*, Vol. 18 Nos 746, pp. 7-12, doi: 10.1016/j.paid.2005.04.006.

Bikfalvi, A. (2011), "Teamwork in production: implementation, its determinants, and estimates for German manufacturing", *Human Factors and Ergonomics in Manufacturing and Service Industries*, Vol. 21 No. 3, pp. 244-259, doi: 10.1002/hfm.20230.

Bonekamp, L. and Sure, M. (2015), "Consequences of industry 4.0 on human labour and work organisation", *Journal of Business and Media Psycology*, No. 1, pp. 33-40.

Boyatzis, R., Rochford, K. and Cavanagh, K.V. (2017), "Emotional intelligence competencies in engineer's effectiveness and engagement", *Career Development International*, Vol. 22 No. 1, pp. 70-86, doi: 10.1108/CDI-08-2016-0136.

Chryssolouris, G., Mavrikios, D. and Mourtzis, D. (2013), "Manufacturing systems: skills and competencies for the future", *Procedia CIRP*, Elsevier, Vol. 7, pp. 17-24, doi: 10.1016/J.PROCIR.2013.05.004.

Ciolacu, M., Svasta, P.M., Berg, W. and Popp, H. (2018), "Education 4.0 for tall thin engineer in a data driven society", *2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging, SIITME 2017 - Proceedings*, Vol. 2018, pp. 432-437, doi: 10.1109/SIITME.2017.8259942.

Cotet, G.B., Balgiu, B.A. and Zaleschi (Negrea), V.C. (2017), "Assessment procedure for the soft skills requested by Industry 4.0", *MATEC Web of Conferences*, Vol. 121 No. 07005, doi: 10.1051/matecconf/201712107005.

Daft, R.L. (2015), "Organization theory and design", 12th ed., Cengage learning, available at: https://books.google.co.nz/books?hl=en&lr=&id=yPq5BwAAQBAJ&oi=fnd&pg=PR3&dq=organization+theory+and+design+&ots=sYlGl1d8yJ&sig=ru0RfdOrZPve66jQZuu_IMUnaJM#v=onepage&q=organization_theory_and_design&f=false.

Dodge, R., Daly, A., Huyton, J. and Sanders, L. (2012), "The challenge of defining wellbeing", *International Journal of Wellbeing*, Vol. 2 No. 3, pp. 222-235, doi: 10.5502/ijw.v2i3.4.

Eshet-Alkalai, Y. (2004), "Digital Literacy: a conceptual framework for survival skills in the digital era", *Journal of Educational Multimedia and Hypermedia*, Vol. 13 No. 1, pp. 93-106.

Farkas, G. (2003), "Cognitive skills and noncognitive traits and behaviors in stratification processes", *Annual Review of Sociology*, Vol. 29 No. 1, pp. 541-562, doi: 10.1146/annurev.soc.29.010202.100023.

Goffee, R. and Scase, R. (2015), *Corporate Realities (Routledge Revivals): The Dynamics of Large and Small Organisations*, Routledge, London.

Goldin, C. (2016), "Human capital", in *Handbook of Cliometrics*, pp. 55-86, doi: 10.1007/978-3-642-40406-1.

Grant, M.J. and Booth, A. (2009), "A typology of reviews: an analysis of 14 review types and associated methodologies", *Health Information and Libraries Journal*, Vol. 26 No. 2, pp. 91-108, doi: 10.1111/j.1471-1842.2009.00848.x.

Haeffner, M. and Panuwatwanich, K. (2017), "Perceived impacts of industry 4.0 on manufacturing industry and its workforce: case of Germany", *International Conference on Engineering, Project, and Product Management*, Springer International Publishing, pp. 199-208, doi: 10.1007/978-3-319-74123-9_21.

Hanushek, E.A. and Woessmann, L. (2008), "The role of cognitive skills in economic development", *Journal of Economic Literature*, Vol. 46 No. 3, pp. 607-668, doi: 10.1257/jel.46.3.607.

Hanushek, E.A. and Woessmann, L. (2012), "Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation", *Journal of Economic Growth*, Vol. 17 No. 4, pp. 267-321, doi: 10.1007/s10887-012-9081-x.

Hecklau, F., Galeitzke, M., Flachs, S. and Kohl, H. (2016), "Holistic approach for human resource management in industry 4.0", *Procedia CIRP*, Vol. 54, pp. 1-6, The Author(s), doi: 10.1016/j.procir.2016.05.102.

Hecklau, F., Orth, R., Kidschun, F. and Kohl, H. (2017), "Human resources management: meta-study - analysis of future competences in industry 4.0", *Proceedings of the 13th European Conference on Management, Leadership and Governance*, pp. 163-175.

Heckman, J.J. and Kautz, T. (2012), "Hard evidence on soft skills", *Labour Economics*, Vol. 19 No. 4, pp. 451-464, doi: 10.1016/j.labeco.2012.05.014.

Hu, S.J. (2013), "Evolving paradigms of manufacturing: from mass production to mass customization and personalization", *Procedia CIRP*, Vol. 7, pp. 3-8, doi: 10.1016/j.procir.2013.05.002.

Hunter, J.E. (1986), "Cognitive ability, cognitive aptitudes, job knowledge, and job performance", *Journal of Vocational Behavior*, Vol. 29 No. 3, pp. 340-362, doi: 10.1016/0001-8791(86)90013-8.

Kagermann, H., Wahlster, W., Helbig, J. and Hellinger, A. (2013), "Recommendations for implementing the strategic initiative INDUSTRIE 4.0: securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group", *Forschungsunion*, doi: 10.13140/RG.2.1.1205.8966.

Kautz, T., Heckman, J., Diris, R., ter Weel, B. and Borghans, L. (2014), *Fostering and Measuring Skills: Improving Cognitive and Non-cognitive Skills to Promote Lifetime Success*, National Bureau of Economic Research, Cambridge, MA, Vol. 119, doi: 10.3386/w20749.

Koppenborg, M., Nickel, P., Naber, B., Lungfiel, A. and Huelke, M. (2017), "Effects of movement speed and predictability in human–robot collaboration", *Human Factors and Ergonomics in Manufacturing*, Vol. 27 No. 4, pp. 197-209, doi: 10.1002/hfm.20703.

Laker, D.R. and Powell, J.L. (2011), "The differences between hard and soft skills and their relative impact on training transfer", *Human Resource Development Quarterly*, Vol. 22 No. 1, pp. 111-122, doi: 10.1002/hrdq.20063.

Li, X., Li, D., Wan, J., Vasilakos, A.V., Lai, C.F. and Wang, S. (2017), "A review of industrial wireless networks in the context of Industry 4.0", *Wireless Networks*, Vol. 23 No. 1, pp. 23-41, doi: 10.1007/s11276-015-1133-7.

Liu, C., Cao, S., Tse, W. and Xu, X. (2017), "Augmented reality-assisted intelligent window for cyber-physical machine tools", *Journal of Manufacturing Systems*, Vol. 44, pp. 280-286, doi: 10.1016/j.jmsy.2017.04.008.

Liu, Y. and Xu, X. (2016), "Industry 4.0 and Cloud Manufacturing: A Comparative Analysis. Volume 2: Materials; Biomanufacturing; Properties, Applications and Systems", *Sustainable Manufacturing*, Vol. 139, March, 2017 V002T04A016, doi: 10.1115/MSEC2016-8726.

Meyer, G., Brünig, B. and Nyhuis, P. (2015), "Employee competences in manufacturing companies–an expert survey", *Journal of Management Development*, Vol. 34 No. 8, pp. 1004-1018, doi: 10.1108/JMD-06-2014-0056.

Miao, C., Humphrey, R.H. and Qian, S. (2017), "A meta-analysis of emotional intelligence and work attitudes", *Journal of Occupational and Organizational Psychology*, Vol. 90 No. 2, pp. 177-202, 10.1111/joop.12167.

Miranda, J., Mäkitalo, N., Garcia-Alonso, J., Berrocal, J., Mikkonen, T., Canal, C. and Murillo, J.M. (2015), "From the internet of Things to the internet of people", *IEEE Internet Computing*, Vol. 19 No. 2, pp. 40-47, doi: 10.1109/MIC.2015.24.

Mitchell, G.W., Skinner, L.B. and White, B.J. (2010), "Essential soft skills for success in the twenty-first century workforce as perceived by business educators", *Delta Pi Epsilon Journal*, Vol. 52, pp. 43-54, doi: 10.1007/s13398-014-0173-7.2.

Monostori, L. (2014), "Cyber-physical production systems: roots, expectations and R&D challenges", *Procedia CIRP*, Vol. 17, pp. 9-13, doi: 10.1016/j.procir.2014.03.115.

Morrar, R. and Arman, H. (2017), The fourth industrial revolution (industry 4.0): a social innovation perspective, *Technology Innovation Management Review*, Vol. 7 No. 11, pp. 12-20, doi: 10.22215/timreview/1117.

Motyl, B., Baronio, G., Uberti, S., Speranza, D. and Filippi, S. (2017), "How will change the future engineers' skills in the industry 4.0 framework? A questionnaire survey", *Procedia Manufacturing*, Vol. 11, pp. 1501-1509, The Author(s), doi: 10.1016/j.promfg.2017.07.282.

Mourtzis, D. (2018), "Development of skills and competences in manufacturing towards education 4.0: a teaching factory approach", in *International Conference on the Industry 4.0 model for Advanced Manufacturing*, Springer, Cham, pp. 194-210, doi: 10.1007/978-3-319-89563-5_15.

Nathanael, D., Mosialos, S., Vosniakos, G.-C. and Tsagkas, V. (2016), "Development and evaluation of a virtual reality training system based on cognitive task analysis: the case of CNC tool length offsetting", *Human Factors and Ergonomics in Manufacturing and Service Industries*, Vol. 26 No. 1, pp. 52-67, doi: 10.1002/hfm.20613.

Ochs, T. and Riemann, U. (2017), "Industry 4.0: how to manage transformation as the new normal", *The Palgrave Handbook of Managing Continuous Business Transformation*, pp. 245-272, doi: 10.1057/978-1-137-60228-2.

Peter, P.C. (2010), "Emotional intelligence", in *Wiley International Encyclopedia of Marketing*, John Wiley & Sons, Chichester, UK, doi: 10.1002/9781444316568.wiem04017.

Piñol, T.C., Porta, S.A., Arévalo, M.C.R. and Minguella-Canela, J. (2017), "Study of the training needs of industrial companies in the Barcelona Area and proposal of Training Courses and

Methodologies to enhance further competitiveness", *Procedia Manufacturing*, Vol. 13, pp. 1426-1431, doi: 10.1016/j.promfg.2017.09.159.

Pinzone, M., Fantini, P., Perini, S., Garavaglia, S., Taisch, M. and Miragliotta, G. (2017), "Jobs and skills in industry 4.0: an exploratory research", in Lödding, H., Riedel, R., Thoben, K.-D., von Cieminski, G. and Kiritsis, D. (Eds), *IFIP International Conference on Advances in Production Management Systems*, Springer International Publishing, Cham, Vol. 513, pp. 282-288, doi: 10.1007/978-3-319-66923-6_33.

Plonka, F.E. (1997), "Developing a lean and agile work force", *Human Factors and Ergonomics in Manufacturing*, Vol. 7 No. 1, pp. 11-20, doi: 10.1002/(SICI)1520-6564(199724)7:1<11::AID-HFM2>3.0.CO;2-J.

Qin, J., Liu, Y. and Grosvenor, R. (2016), "A categorical framework of manufacturing for industry 4.0 and beyond", *Procedia CIRP*, Vol. 52, pp. 173-178, doi: 10.1016/j.procir.2016.08.005.

Rezvani, A., Chang, A., Wiewiora, A., Ashkanasy, N.M., Jordan, P.J. and Zolin, R. (2016), "Manager emotional intelligence and project success: the mediating role of job satisfaction and trust", *International Journal of Project Management*, Vol. 34 No. 7, pp. 1112-1122, doi: 10.1016/j.ijproman.2016.05.012.

Robles, M.M. (2012), "Executive perceptions of the top 10 soft skills needed in today's workplace", *Business Communication Quarterly*, Vol. 75 No. 4, pp. 453-465, doi: 10.1177/1080569912460400.

Rojko, A. (2017), "Industry 4.0 concept: background and overview", *International Journal of Interactive Mobile Technologies (IJIM)*, Vol. 11 No. 5, pp. 77-90, available at: http://online-journals.org/index.php/i-jim/article/view/7072/4532.

Romero, D., Bernus, P., Noran, O., Stahre, J. and Berglund, Å.F. (2016), "The operator 4.0: human cyber-physical systems and adaptive automation towards human-automation symbiosis work systems", *IFIP Advances in Information and Communication Technology*, September, pp. 677-686, doi: 10.1007/978-3-319-51133-7_80.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M. (2015), "Industry 4.0: Future of Productivity and Growth in Manufacturing", *Boston Consulting Group (BCG)*, April, pp. 54-89, doi: 10.1007/s12599-014-0334-4.

Sackey, S.M. and Bester, A. (2016), "Industrial engineering curriculum in industry 4.0 IN a South African context", *South African Journal of Industrial Engineering*, Vol. 27 No. 4, pp. 175-189, doi: 10.7166/27-4-1579.

Schmidt, F.L. (2002), "The role of general cognitive ability and job performance: why there cannot Be a debate", *Human Performance*, Vol. 15 Nos 1–2, pp. 187-210, doi: 10.1080/08959285.2002.9668091.

Schulz, B. (2008), "The importance of soft skills: education beyond academic knowledge", *NAWA Journal of Language and Communication*, available at: http://hdl.handle.net/10628/39.

Seshia, S.A., Sadigh, D. and Sastry, S.S. (2015), "Formal methods for semi-autonomous driving", in *Proceedings of the 52nd Annual Design Automation Conference on-DAC '15*, ACM Press, NY, pp. 1-5, doi: 10.1145/2744769.2747927.

Shariatzadeh, N., Lundholm, T., Lindberg, L. and Sivard, G. (2016), "Integration of digital factory with smart factory based on internet of Things", in *Procedia CIRP*, Elsevier B.V, Vol. 50, pp. 512-517, doi: 10.1016/j.procir.2016.05.050.

Smirnov, A., Levashova, T., Shilov, N. and Sandkuhl, K. (2014), "Ontology for cyber-physical-social systems self-organisation", in *Conference of Open Innovation Association*, FRUCT, Vol. 2014, December, FRUCT Oy, pp. 101-107, doi: 10.1109/FRUCT.2014.7000933.

UK, E. (2016), *Digital skills for the UK economy*.

URCIUOLI, B. (2008), "Skills and selves in the new workplace", *American Ethnologist*, Vol. 35 No. 2, pp. 211-228.

van Dijk, J.A.G.M. (2006), "Digital divide research, achievements and shortcomings", *Poetics*, Vol. 34 Nos 4–5, pp. 221-235, doi: 10.1016/j.poetic.2006.05.004.

Van Dijk, J. and Hacker, K. (2003), "The digital divide as a complex and dynamic phenomenon", *Information Society*, Vol. 19 No. 4, pp. 315-326, doi: 10.1080/01972240309487.

Vuorikari, R., Punie, Y., Carretero, S. and Van Den Brande, L. (2016), "DigComp 2.0: the digital competence framework for citizens. Update phase 1: the conceptual reference model", *EU Commission JRC Technical Reports*, doi: 10.2791/11517.

Wan, J., Cai, H. and Zhou, K. (2015), "Industrie 4.0: enabling technologies", in *Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things*, IEEE, ICIT Vol. 2015, pp. 135-140, doi: 10.1109/ICAIOT.2015.7111555.

Weilkiens, T. (2015), "Soft skills", in *Model-Based System Architecture*, John Wiley & Sons, Hoboken, NJ, USA, pp. 291-310, doi: 10.1002/9781119051930.ch20.

Xu, X. (2017), "Machine Tool 4.0 for the new era of manufacturing", *International Journal of Advanced Manufacturing Technology*, Vol. 92 Nos 5–8, pp. 1893-1900, doi: 10.1007/s00170-017-0300-7.

Zhang, A. (2012), "Peer assessment of soft skills and hard skills literature Review: challenges and demands", *Journal of Information Technology Education: Research*, Vol. 11, pp. 155-168.

Zhang, J., Yu, P.S. and Lv, Y. (2015), "Organizational chart inference", *Proceedings of the 21th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, pp. 1435-1444, doi: 10.1145/2783258.2783266.

Zhong, R.Y., Xu, X., Klotz, E. and Newman, S.T. (2017), "Intelligent manufacturing in the context of industry 4.0: a review", *Engineering*, Vol. 3 No. 5, pp. 616-630, doi: 10.1016/J.ENG.2017.05.015.

Zhou, J., Li, P., Zhou, Y., Wang, B., Zang, J. and Meng, L. (2018), "Toward new-generation intelligent manufacturing", *Engineering*, Vol. 4 No. 1, pp. 11-20, doi: 10.1016/J.ENG.2018.01.002.

Corresponding author
Emmanuel Flores can be contacted at: ntor030@aucklanduni.ac.nz