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Organisational Learning and Industry 4.0: Findings from a Systematic Literature Review and Research Agenda

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Abstract

Purpose – Industry 4.0 has been one of the most topic of interest by researches and practitioners in recent years. Then, researches which bring new insights related to the subjects linked to the Industry 4.0 become relevant to support Industry 4.0's initiatives as well as for the deployment of new research works. Considering "Organisational Learning" as one of the most crucial subjects in this new context, this article aims to identify dimensions present in the literature regarding the relation between Organisational Learning and Industry 4.0 seeking to clarify how learning can be understood into the context of the fourth industrial revolution. In addition, future research directions are presented as well.

Design, methodology/ approach – This study is based on a systematic literature review (SLR) that covers Industry 4.0 and Organisational Learning based on publications made from 2012, when the topic of Industry 4.0 was coined in Germany, using as data basis Web of Science and Google Scholar. Also, Nvivo software was used in order to identify keywords and the respective dimensions and constructs found out on this research.

Findings – Nine dimensions were identified between Organisational Learning and Industry 4.0. These include Management, Industry 4.0, General Industry, Technology, Sustainability, Application, Interaction between Industry and the Academia, Education and Training, and Competency and Skills. These dimensions may be viewed in three main constructs which are essentially in order to understand and manage Learning in Industry 4.0's programs. They are: Learning Development, Industry 4.0 Structure and Technology Adoption.

Research limitations/Implications – Even though there are relatively few publications that have studied the relationship between Organisational Learning and Industry 4.0, this article makes a material contribution to both the theory in relation to Industry 4.0 and the theory of learning - for its unprecedented nature, introducing the dimensions comprising this relation as well as possible future research directions encouraging empirical researches.

Practical implications – This article identifies the thematic dimensions relative to Industry 4.0 and Organisational Learning. The understanding of this relation has a relevant contribution to professionals acting in the field of Organisational Learning and Industry 4.0 in the sense of affording an adequate deployment of these elements by organisations.

Originality/value – This article is unique for filling a gap in the academic literature in terms of understanding the relation between Organisational Learning and Industry 4.0. The article also provides future research directions on learning within the context of Industry 4.0.

Keywords: Industry 4.0, Learning, Manufacturing Industry, Technology, Organisational Learning.

Paper Type – Literature Review

1. Introduction

Industry 4.0 is a "strategic initiative" of the German government adopted as part of the 2020 High Technology Strategy Action Plan in November 2011 (Ardito *et al.*, 2019), even though, since 2006, the purpose has been to promote the effective integration of Industry 4.0, encompassing aspects such as Internet of Things, Cloud Computing, Big Data Analysis; Cyber Security; profiles of internal and external clients in organizations (Lu, 2017).

It should be taken into account that, since 2006, the German government had been seeking a high technology strategy targeted at the coordination of interdepartmental research and innovation initiatives, with the objective of guaranteeing a strong competitive position for Germany through technological innovation (Yang *et al.,* 2018). Among the characteristics of companies in the Fourth Industrial Revolution is the fact that they are intelligent, connected and act in strategic areas.

The focus of Industry 4.0 is on technological products, more agile procedures and processes, in complex environments and subject to disruption and deflection. One of its objectives is to connect human beings, machines and equipment in a large communication network, targeting mobility, flexibility and the establishment of intelligent networks, promoting vertical and horizontal integration (Kagermann *et al.,* 2013; Bauer *et al.,* 2018). According to Bienhaus and Haddud (2018), the digitalization process may bring a number of benefits, including: support for daily administration and business tasks, support for complex decision-making processes, acquisitions will become more focused on strategic decisions and activities. This scenario of Industry 4.0 is changing the way of learning in organizations and in the academia (Schuh *et al*., 2015; Simons *et al*., 2017).

Significant researches have been developed on the context of Industry 4.0 such as Sustainability (Kamble, Gunasekaran and Gawankar, 2018; Jabbour et al., 2018), Lean Manufacturing (Sanders, Elangeswaran and Wulfsberg, 2016; Mrugalska and Wyrwicka, 2017), Product Development (Santos et al., 2017), Small and Medium Enterprises - SMEs in Industry 4.0 (Moeuf, 2017), Production Planning and Control (Dolgui, et al., 2018), Strategic Management (Lin et al., 2018), Performance Measurement (Frederico, et al.,2020), Organisational Structure (Wilkesmann and Wildesmann, 2018), Servitization (Frank et.al.,

2019) and Supply Chain and Industry 4.0 (Frederico et al., 2019; Büyüközkan and Göçer, 2018 and Kache and Seuring, 2017).

Also research efforts related to the main disruptive technologies of Industry 4.0 have been undertaken giving significant theoretical and practical contributions such as on Big Data Analytics (Queiroz and Telles, 2018; Wamba et al. 2015; Gunasekaran et al., 2017; Hazen et al., 2016) and Internet of Things – IoT (Gunasekaran, Subramanian and Tiwari, 2016; Misrha et al.,2016; Ben-Daya, Hassini and Baroun, 2017).

On the sense of the subject of this article, individual and Organisational learning within the context of Industry 4.0 is a mandatory aspect in managing complex industrial processes, in which different tasks are carried out by different partners in separate geographic spaces, both intra and inter organizations. According to Ardito *et al.* (2019), Industry 4.0 has had positive reflexes in the deployment of Information Technology (IT). Currently, approximately 90% of all manufacturing processes already have some form of IT support. Organizations have experimented a number of different ways of disseminating information, with the new technologies associated to the principles of Industry 4.0, which are capable of promoting data and information integration and interoperability among different companies in decision-making (Chen *et al.*, 2008; Aydin, 2018).

For Al-Kurdi *et al.* (2018), Organisational culture is fundamental in promoting knowledge and information sharing, with Industry 4.0 focusing on creating intelligent products, procedures and processes that enable managing complexity with a lower trend to interruptions, manufacturing goods more efficiently. In intelligent plants, humans, machines and resources communicate with each other with the same naturality as in social media (Ardito *et al.*, 2019; Tvenge and Martinsen, 2018). In order to survive in such a complex environment, companies must be extremely agile and build high levels of capability in resilience and risk mitigation and structural flexibility enabling a quick response to these challenges (Ben-Dayaa *et al.*, 2017; Soomro *et al.*, 2019).

Based on this scenario, authors like Wagner *et al.* (2012), Hummel *et al.* (2015), Yang *et al.* (2018), emphasize that concepts related to intelligent factories have been gaining more relevance due to the Industry 4.0, concepts connected to the so-called Learning Factories determined by digital technologies, such as the Internet of Things, Big Data and Artificial Intelligence.

Industry 4.0's continual professional qualification and development is, currently, one of the priority action areas (Enke *et al*., 2015). The outcome of the implementation of Industry 4.0 should be a social-technical plant driven to work and the working system (Kagermann *et al.*, 2013). Nonetheless, Organisational learning is an issue that should be approached in its full complexity, implying in innovations in academic training and in the ongoing professional development, above all in the areas of engineering, caused by the changes in employment profiles and the competencies in the world of work. Thus, the idea of learning is far broader than just training, given it involves the lifelong development of competencies and learning (Schein, 1996; McHugh *et al*., 1998; Baker and Sinkula, 1999; Hancock and Tyler, 2008; Kagermann *et al*., 2013; Steinbuß *et al*., 2017; Simper *et al*., 2018). Yet, Organisational Learning has a positive mediation between the Industry 4.0's initiatives and Operational Performance (Tortorella *et al*., 2020).

Also, Organisational learning may be supplemented by a cultural dimension, comprised of Organisational values or postures (Schein, 1996). In organizations, this may be an ideology of support for a management Organisational development agenda, often decentralized and in post-bureaucratic formats, that explore their workers and transform students into self-disciplining collaborators (McHugh *et al*., 1998; Hancock and Tyler, 2008). For McHugh *et al*. (1998) the learning process in organizations leads individuals to acquiring knowledge, values, behaviors and skills by way of being taught and studying. For Baker and Sinkula (1999), in its turn, the drive to learning affects directly the capacity to challenge statements or old "truths" about the Market and how companies should be organized to deal with them.

Thus, given the previously set out context, this research targets answering the following question:

How Organisational Learning can be understood in the context of Industry 4.0?

This article aims to understand how the Organisational learning can be viewed in the context of Industry 4.0, showing the dimensions from this understanding which supports on the management of learning in Industry 4.0 initiatives as well as on the deployment of future research directions.

Some researches related to this subject has already been published, such as future research in management, production management, and industrial organizations (Nosalska *et al*., 2019), process design principles, providing guidelines for the design and management of Industrie 4.0 compliant processes (Hermann *et al*., 2019), the success factor, failure factor, business model, potential and difficulties in the context of Industry 4.0 (Rejikumar *et al*., (2019), an integrative system of value creation that is comprised of 12 design principles and 14 technology trends (Ghobakhloo, 2018), a research agenda where a common terminology should be created and the consequences of human resources should be analyzed (Erro-Garcés, 2019), six broad themes of readiness factors (Sony and Naik, 2019), to propose a taxonomy of Industry 4.0 research landscape (Wagire *et al*., 2019), but without mentioning the initiative of academic learning in the context of Industry 4.0.

However, this paper seeks to give a more holistic view, which is a significant gap, from the compilation of the literature available, building a consolidated knowledge related to Learning in Industry 4.0.

Therefore, the article is structured as follows: I) Introduction with approach of Industry 4.0 and Organisational Learning as shown above. II) Systematic Literature Review with the due data collection and analysis. III) Discussion of findings from the literature review. IV) Conclusion and possible future research directions based on the dimensions identified in this study.

2. Systematic Literature Review

This review of the literature is a scientific and transparent process that can be replicated, i.e., the technique outlined, that has the intent of minimizing learning risks and difficulties. As mentioned by Tranfield *et al.* (2003), the review of the literature may be the most important part of any research project. Researchers map and evaluate important problem issues to be studied that then lead to developing the questions that further contribute to enhancing the science of knowledge. Through past research, current reality may be improved and prepared for a near future (Webster and Watson, 2002). Using the gaps found through literature reviews serves as source of insights and direction for the permanent benefit of operating needs of those who would use the study as a strategy model to be followed as a guide in the organizations that learn.

Through exhaustive bibliography search of studies published previously, or as yet unpublished, researchers are able to define paths to be followed (Tranfield *et al*., 2003). The method applied in this study followed the one proposed by Tranfield *et al*. (2003) based on three stages: (I) planning the review, (II) performing the review, (III) reporting and disclosing results. As starting point, publications on the topic of "Industry 4.0" or "Industrie 4.0" and "learning" on the Web of Science and on Google Scholar, between 2012 and 2019, were identified. This period was chosen considering that the interest by Industry 4.0 by for both practitioners and academics started from 2012, after the concept has been presented in the Hannover Fair in 2011 in Germany.

Liao *et al.* (2017) mention the fact that, for a systematic literature review to be viable, the concepts must be explicitly stated. According to Aydin (2018), the focus of Industry 4.0 lies in technological products, more agile procedures and processes, in a complex environment subject to disruption and deflection. One of its objectives is to connect humans, machines and equipment, in short, the different resources in a large communication network, targeting mobility, flexibility and the establishment of intelligent networks, with vertical and horizontal integration (Al-Kurdi *et al*., 2018). However, learning by everyone becomes fundamental for this connection to take place.

Therefore, this paper's main contribution is to introduce the dimensions in the relation between Organisational Learning and Industry 4.0, which provides the view in how learning should be understood into this fourth industrial revolution context. Nonetheless, another important contribution of this paper is to provide future research directions on this relation, contributing to future researches related to this topic, from the compilation presents in this literature review.

Table 1 shows the stages of the article search process for those that comprise the corpus under analysis

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[Table 1 – Insert here]

2.1 Data collection and analysis

The analysis period covered in this study went from 2012 to 2019, when the term Industry 4.0 gained interests by researchers and practitioners after it has been launched on the Hannover fair in 2011.

On the search, 50 documents were found in the Web of Science and Google Scholar database with the words "learning" and "industry 4.0" or "industrie 4.0" and published within the time period set out in Table 2. There is a higher concentration of publications in 2017 (32%), followed by 2015 and 2017 (30%). No publications were found in 2013 and 2014.

[Table 2 – Insert here]

The study also evidenced that conferences on Learning Factories in 2015, 2017 and 2018 displayed the highest frequencies of publications, respectively. This is explained by the fact that the interest by this research topic started from 2012 and researches, generally are first communicated in refereed conferences. Table 3 shows the distribution of documents by events or journals. The authors opted for conferences to identify the research agenda, which can generate more robust scientific articles in the future. This scope is one of the limitations of this research, although it presents relevant questions for researchers in the coming years.

[Table 3 – Insert here]

In this study, the NVivo software was used in performing the systematic review of the target literature in terms of keyword analysis. In the keyword analysis in the 50 documents, 126 unique keywords were found in the articles (Appendix I), showing a dispersion concerning the topics approached in these articles.

3. Findings from Literature Review

In this section, the main findings in the contents of the documents analyzed in this literature review will be shown. The most frequent words on the articles were identified based on Nvivo software. They were grouped into similar categories, that is, they are related with the same subject by their genre. The 21 keywords most evidenced in the analyzed articles are displayed below, with frequency in parentheses: Learning Factory (23), Industry 4.0 (20), Industrie 4.0

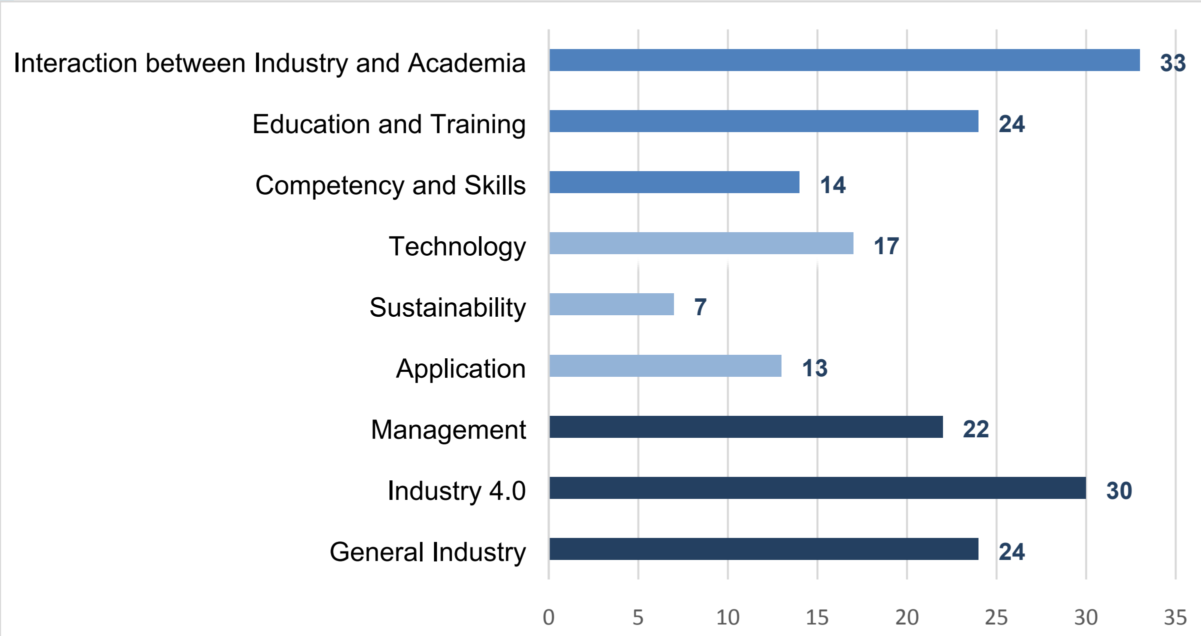
(7), Learning Factories (7), Cyber-Physical Systems (4), Digitalization (4), Energy Efficiency (4), Logistics (3), Manufacturing Education (3), Manufacturing Engineering (3), Training (3), Competence Development (2), Cyber-Physical Production Systems (2), Digital Transformation (2), Education (2), E-Learning (2), Lean Management (2), Lean Manufacturing (2), Production Planning And Control (2), Project-Based Learning (2), Engineering Education (2).

After analyzing the content of these 50 articles, these 126 keywords indicated by the authors of the articles (APPENDIX I) were grouped by similar ideas. The dimensions presented in the subject Learning in Industry 4.0 were identified in content analysis.

Figure 1 introduces the nine dimensions created by the authors, based on the grouping of keywords with similarity, to wit: Management, Industry 4.0, General Industry, Technology, Sustainability, Application, Interaction between Industry and Academia, Education and Training, and Competency and Skills. The tables 4, 5 and 6 present these keywords, as well as their content.

Figure 1 presents the number of articles which considered each dimension, taking into consideration that that an article can have multiple keywords. These dimensions represent the elements that were considered by the set of authors who has studied about Learning in Industry 4.0. These dimensions provide a holistic view regarding how learning can be viewed in order to support Industry 4.0's initiatives, which will be presented below.

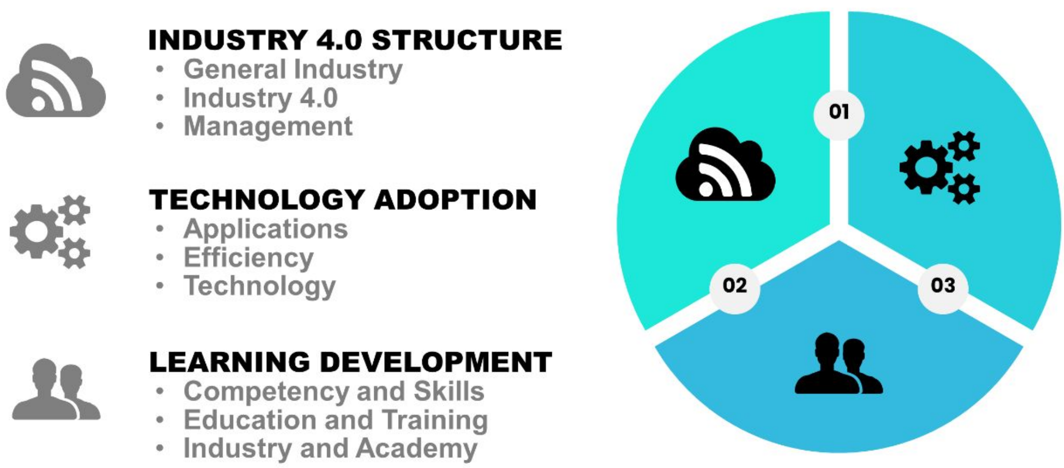
Figure 1 - Dimensions between Organisational Learning and Industry 4.0 formed by the keywords indicated by the authors in their articles extracted from literature review



On the sequence, some ideas found in the analysis categories comprising the constructs under study will be introduced. The first one **(Industry 4.0 Structure)** concerns aspects in connection with the enhancement of industrial and general administration. The second one (**Technology Adoption**) deals with aspects linked to technology and its applications, as well as aspects involving increased efficiency and reduced energy consumption. The third (**Learning Development**) is about the interaction between university and industry, the strategies in education and training for students and professionals, as well as the development of competencies and skills within the context of Industry 4.0.

These nine dimensions (Figure 1) were grouped in three main constructs according to Figure 2. They are related through the rationale that education and training for both, practicing professional and students, in developing competencies and skills, must provide support for the application of new technologies given the increase in efficiency seen in the Industry 4.0 initiatives.

Figure 2 – Constructs between Organisational Learning and Industry 4.0



3.1 Industry 4.0 Structure

The first dimension states that management techniques must be enhanced in Industry 4.0 and in industry at large. The man-machine interfaces remain typical of Industry 3.0 both in the automation process, and in the digitizing process and in autonomous systems of Industry 4.0. According to the stated in Table 4, in each analysis category keywords appointed by the authors in the documents have been grouped.

[Table 4 – Insert here]

Several types of application for Industry 4.0 have been introduced since 2011, when Hannover Messe took place, according to Wank *et al*. (2016). The main focus of learning in Industry 4.0 is digitizing, followed by the following challenges: horizontal integration, deployment of digital engineering among partners, vertical integration, establishment of new social infrastructures and implantation of cyber-physical production systems (Schallock *et al.*, 2018). Industry 4.0 presupposes the existence of management practices such as the Lean philosophy, employee participation in decision making, knowledge exchange among the staff, among others.

The objective of learning in Industry 4.0 is the creation of fairly realistic simulation plant environments, above all in Learning Factory environments. Cachay *et al*. (2012) approached learning by engineering students in these environments and identified that, despite the principles of the Bologna Agreement in Europe, study at university level still remains very abstract and scientific in developing competencies for acting on the work market, i.e., there are shortcomings in the integration among the technical, process and conceptual knowledge types.

For Wagner *et al*. (2015), the Learning Factory is the appropriate venue for studies on the efficient use of resources. In addition, this initiative concentrates in several fields such as lean management, quality management, logistics, capacity for change in production, resilience, strategic leadership among others, always with the objective of sharing specialized knowledge (Uhlemann *et al*., 2017).

3.2 Technology Adoption

The second dimension pools keywords dealing with technologies, such as the Internet of Things and digitizing, the deployment of these technologies in industry with the objective of increasing energy efficiency, for instance. According to Table 5, one of the new markers of the new industry will be the use of 3D printers, cyber-physical systems, mass digitizing, in addition to the use RFId and Raspberry Pi.

[Table 5 – Insert here]

Learning of practical applications in Industry 4.0 is encouraged using techniques like machine learning, debriefing, digital twin, scale modelling, for professionals and students. Focused on technology, Industry 4.0 also requires product and service knowledge such as 3D printing, RFID, Augmented reality, Internet of Things, Cyber-physical systems, assistance systems, Raspberry Pi, with the intent of promoting integration among automated systems (Elbestawi *et al*., 2018).

The concept of Lear instrument was introduced by Muschard and Seliger (2015) through the CubeFactory equipment, in which users can operate them intuitively and practically, with a view to expanding their knowledge independently. This solar powered equipment integrates a 3D printer and a recycler for producing filaments. This 1m^3-equipment, suitable for sites with infrastructure shortcomings, features some environmental advantages such as reduction of waste, low consumption, low CO^2 emissions, production in environments close to consumption, in addition to flexibility in customizing production. The CubeFactory was developed under the people-centered design concept, enabling deployment in precarious infrastructure sites, in additional to allowing operation by people with little prior knowledge.

In its turn, learning focused on cost optimization and reduction was approached Schallock *et al*. (2018). According to the authors, in addition to operational training, it is necessary to focus on broader topics, such as management, coaching and effective monitoring of work after training. Their studies approach the learning factory, developed mainly in Europe in the last ten years and that integrates observation, theory and practice in qualifying engineering students and professionals. In studies of energy efficiency in industry, Büth *et al.* (2018) introduced some analysis methods, such as: load curve analysis, load duration curve analysis, machine lists, pareto analysis, Sankey diagrams, energy portfolio, energy value stream analysis and energy break down analysis.

Starting from cyber-physical systems, a partial reversion of Taylorism (Reverse Taylor) will be possible, affirm Bauernansl *et al*. (2018), for the following characteristics: manufacture supported by planning and execution standards, co-design process between manufacturer and customer, fluid areas of competency for professionals that change over time and be supported by cyber-physical systems (CPS). The authors affirm that cyber-physical systems (CPS) are capable of helping in competency development, and this requires new models of learning, including through the use of distance education and learning based on shopfloor practices.

In energy intensive production industries, developing competencies for reduction of energy consumption may become a competitive advantage, according to Kaluza *et al.* (2015). Thus, the study of energy efficiency can be an important element to be addressed in learning at the factory, because all forms of energy must be included in studies in connection with their economic and ecological impacts, in processes like machining, mechatronics, robotics or assembly (Kaluza *et al*., 2015).

Studies on decision-making for energy efficiency between management levels (top-floor and shop-floor) were undertaken by Faller and Fedmüller (2015). The following are among the objectives reported in the study: optimization strategies analyzed using performance indicators (KPI); energy metering equipment functionalities and configuration; energy monitoring software are handled by students; efficient manufacturing means are demonstrated; in addition, people learn to put in place energy efficiency devices in their companies.

Digitizing has the power of increasing efficiency in Industry 4.0, affirm Büth *et al*. (2018), above all if human beings take on the central role in planning manufacture processes. The authors investigated whether digitizing has a positive effect on the operation of energy transparency and demand visibility tools.

Thus, qualification and training for professionals in evaluating these tools becomes necessary, given the existence of an economic cap for the degree of energy transparency, after which the efforts required to implement acquisition, operating and maintenance costs outweigh the potential benefits, according to Büth *et al*. (2018). Energy efficiency optimization and lean management are among the most commonly approached topics in plants, affirms Rentzos *et al*. (2015).

Plorin *et al.* (2015)'s article introduced two examples of application of advanced learning factory: energy efficiency in manufacture and global production management. The capacity for quick response to changes is one of the interlinked systems in Industry 4.0. In learning factories, individual staff efficiency, process improvement and efficient use of resources for the purpose of delivering targets, reducing manufacturing costs, in addition to increasing output quality and speed (Wank *et al.*, 2016).

The active use of assistance systems, within the context of cyber-physical systems, was approached by Prinz *et al*. (2017), with a view to increasing efficiency and reducing waste. Assistance systems are one of the solution areas present in Industry 4.0, together with centralization, service driven, autonomy, data acquisition and processing, networking and integration (Prinz *et al*., 2017).

3.3 Learning Development

Interaction between industry and university targets establishing an environment as close as possible to the reality of the workplace, as well as meaningful educational contents for college students. To this end, Learning Factories were created as one of the initiatives in academia – industry integration. Through active learning techniques, on-site or remote, education initiatives connect professors to plant professionals in teaching new manufacturing methods to students and professionals. Table 6 shows the main ideas presented in documents in connection with education and learning in competency development within the context of Industry 4.0.

[Table 6 – Insert here]

Research results by Motyl *et al*. (2017) evidence that Italian college students display a good relationship with digital devices and good knowledge of topics such as Virtual Reality; Augmented Reality; Mixed Reality; Rapid Prototyping; 3D Printing; FABLAB; Industry 4.0; Smart factories. These new skill sets are important for students who will be working in an increasingly more globalized, automated, virtualized and flexible world. However, are universities preparing professionals for these new challenges?

The Learning Factory, according to Wagner *et al*. (2015), is an experience that develops professional competencies in relation to work management, participation and organization, in addition to being focused on process improvement and efficient use of resources. The educational paradigm in connection with manufacture must be updated to face the emerging challenges in Industry 4.0, from the standpoint of current concepts in industrial training, learning and transfer of knowledge, affirm Abele *et al*. (2017). This new personal competency development paradigm must take into account: training in more realistic manufacturing environments, bring learning closer to industrial practices, enhance industrial practices through the adoption of new manufacturing technologies, increase the industry's innovation capacity through problem solving, creativity and holistic perspective of reality. The experiential learning cycle was mentioned by Tvenge and Ogorodnyk (2018) and consists in four stages: (I) concrete experience, (II) reflexive observation, (III) abstract conceptualization, and (IV) active experimenting; after this, the cycle starts over. The authors mentioned something that is little used in industrial education (manufacturing education): debriefing, a technique that can help in identifying best practices, as well as identifying improvements through industrial simulation.

The development of learning in Industry 4.0 has been observed to target competency development, both for professionals, and students. In order for this to take place, a number of education strategies may be present such as e-learning, informal learning and social learning. Learning must be an active process focused on experience, with streams such as game-based learning, hybrid learning or hands-on education. Action-based learning can be used in academic and professional qualification, whereby students are qualified to internalize knowledge and develop practical skills through self-defined actions in a simulated factory environment (Kaluza *et al*., 2015).

Employees, Technology and Organization were the three variables in Learning Factory presented by Wagner *et al*. (2015). In a simulation about production improvement, students worked on the complexity of labor regulation in a negotiation activity between organization and employees; not dealing with just technological improvement and higher efficiency issues. Plorin *et al.* (2015) introduced a proposal for advanced learning factory (aLF) as a reference model for learning in Industry 4.0. The authors have established eight steps in the design of this learning: (I) identification of the current learning environment, (II) deriving use cases, (III) deriving learning modules, (IV) combination of competencies for the learning environment, (V) structure of target group profile competencies, (VI) configuration and parameter definition for learning modules, (VII) design of the learning environment, (VIII) integration with existing learning environment. The research done by the Motyl *et al*. (2017) team looked into three Italian universities to establish the skills and knowledge required for young engineers in the context of the Fourth Industrial Revolution.

Learning can also be offered by the teaching factory, a practical integration experience between university and industry, with origin stemming from teaching methods used in the healthcare area. With a view to a more realistic education, with synchronous and asynchronous moments from factory-to-classroom and other from university to a industry (academy-to-industry). Simulation may be an experience-driven form of learning, according to Tvenge and Ogorodnyk (2018) and is being used in industrial learning for years for representing a practical perspective on teaching. The authors mention debriefing as an important aspect in creating reflexive students. Debriefing is defined as a facilitator-led simulation experience. Students are encouraged to reflect on the simulation and share with other participants, in addition, there is feedback about their performance (Tvenge and Ogorodnyk, 2018).

According to Figure 1 which shows the frequency distribution among the nine dimensions mentioned by the authors in keywords, the topic of sustainability was little mentioned in the keywords, as well as the development of competency and skills. A more in-depth study of the content of texts may clarify how education and training are associated to the development of competencies and skills in Industry 4.0.

3.4 Research agenda

In closing, questions for future research were collected from articles on the relation between Learning and Industry 4.0, found in this systematic literature review, shown in Tables 7, 8 and 9, stemming from each of the three constructs, distributed by chronological order of publication. Table 7 displays the questions for future studies on the construct Learning Development.

These questions were identified by the reading of the articles considered to data analysis. Each one of these questions is proposed as the suggestions made by the respective authors according to the three next tables. Then, Table 7, 8 and 9 were built by the compilation of the set of suggestions collected from the data analysis.

[Table 7 – Insert here]

Table 8 presents questions for future studies in relation to construct Industry 4.0 Structure.

[Table 8 – Insert here]

Table 9 presents questions for future studies in relation to construct Technology Adoption

[Table 9 – Insert here]

The compilation of future studies indicated in these conferences can serve as a parameter to check the evolution of learning and training initiatives in the context of Industry 4.0 in the next years. Hence, future studies on Organisational Learning and Industry 4.0, grouped into three constructs, have been suggested. The development of competencies and skills should be associated with the application of new technologies and the managerial models of efficiency increase, as well as in the improvement of the interface between the academy and the industry through initiatives like Learning Factory or Teaching Factory. This should be part of industry strategy and university educational planning.

4. Conclusions

Ongoing training and professional development in the context of Industry 4.0 may be one of today's priority areas. Organisational Learning in the context of the Fourth Industrial Revolution is an important component of business transformation in the digital age, with a focus on technological products, procedures and processes that are more agile, in an environment of complexity and integration among different organizations.

This systematic literature review identified 50 articles on the topic of Organisational Learning in Industry 4.0 in the Web of Science and Google Scholar databases, in particular publications in events about Learning Factory, with a higher incidence in the title and keywords. One of the main limitations of this article is that the data found is mostly focused on Learning Factory approaches, as well as coming from publications in conferences with reports of learning experiences in Industry 4.0.

Then, future literature reviews should be undertaken in order to get more understanding related to learning in other fields of Industry 4.0's applications, such as supply chain and logistics, services, amongst others. It is also important to emphasize that the majority of articles are from refereed events due to the emergent topic of research. Then, having this as another limitation, as this subject is better developed along the next years by academics and practitioners new insights may be provided regarding Organisational Learning in the Industry 4.0's context in future literature reviews conduction. Also, this study comes from its qualitative and exploratory character, in which it is not possible to generalize the constructs presented. Studies on Organisational Learning and Industry 4.0 are still incipient, with the presentation of papers at conferences. The research agenda presented at conferences on Organisational Learning and Industry 4.0 may not be further explored in scientific articles in the future, and this is one of the limitations of this research. Future studies can evaluate the result of the learning initiatives in the context of Industry 4.0 in articles.

Nine dimensions were identified between Organisational Learning and Industry 4.0, to wit: Management, Industry 4.0, General Industry, Technology, Sustainability, Application, Interaction between Industry and Academia, Education and Training, Competencies and Skills, which were divided into three constructs: Learning Development, Industry 4.0 Structure and Technology Adoption. From these constructs and their developments, it is possible to identify main areas which need to be considered in order to effectively understand and manage Learning in Industry 4.0's programs supporting on its Strategic establishment.

4.1 Practical Implications

As a practical implication, there is the need to adapt university curricular content, especially in the area of engineering, to the requirements of new technologies associated with Industry 4.0, such as 3d printing, assistance systems, augmented reality, automation, cyber-physical systems, digital transformation, digitalization and internet of things.

The continuous training of professionals and students is necessary in an industrial system in constant technological changes, which requires competence for new learning, as well as the skills to implement new systems targeted at increasing industrial efficiency, such as action orientation, active and collaborative learning, constructivism, e-learning, game-based learning, hands-on education, problem-based learning, simulation, and work-based learning.

In addition, this study presents guidelines for the people skills development to be included in training and industrial training programs, such as digital skills, capability building, interaction, knowledge interdisciplinary, and skills socio-technical. It provides a significant contribution to lifelong learning strategies in Industry 4.0's initiatives.

4.2 Theoretical Implications

Research questions have also been identified for future studies in relation to each of the three constructs (Learning Development, Industry 4.0 Structure and Technology Adoption). These questions are described on Table 7, 8 and 9. Special attention should be given to other areas of knowledge because a holistic view of learning in the context of Industry 4.0 should be taken into consideration and not remain focused solely on the areas of engineering. Future studies may also address the socio-technical, cultural, administrative, social, and environmental implications of the impact of the deployment of Industry 4.0 and its technologies on people's competence development.

Significant researches have been developed on the context of Industry 4.0 such as Sustainability (Kamble, Gunasekaran and Gawankar, 2018; Jabbour et al., 2018), Lean Manufacturing (Sanders, Elangeswaran and Wulfsberg, 2016; Mrugalska and Wyrwicka, 2017), Product Development (Santos et al., 2017), Small and Medium Enterprises - SMEs in Industry 4.0 (Moeuf, 2017), Production Planning and Control (Dolgui, et al., 2018), Strategic

Management (Lin et al., 2018), Performance Measurement (Frederico, et al.,2020), Organisational Structure (Wilkesmann and Wildesmann, 2018), and Supply Chain and Industry 4.0 (Frederico et al., 2019; Büyüközkan and Göçer, 2018 and Kache and Seuring, 2017).

Also, significant research efforts related to the main disruptive technologies of Industry 4.0 have been deployed such as Big Data Analytics (Queiroz and Telles, 2018; Wamba et al. 2015; Gunasekaran et al., 2017; Hazen et al., 2016) and Internet of Things – IoT (Gunasekaran, Subramanian and Tiwari, 2016; Misrha et al.,2016; Ben-Daya, Hassini and Baroun, 2017).

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APPENDIX I

[Appendix I – Insert here]

Table 1 – Steps of Systematic Literature Review based on Tranfield *et al*. (2003)

Planning the review (I)		
Database search	***Web of Science***	***Google Scholar***
Words	*("learning" and "industry 4.0" or "industries 4.0")*	*("learning" and "industry 4.0" or "industries 4.0")*
Place	*Article title, Abstract, keywords.*	*Article title, Abstract, keywords.*
Years	2012 a 2019	2012 a 2019
Conducting a review (II)		
Finding	proceedings papers (457) and articles (185).	Proceedings papers and articles (345).
Refining	Reading of title, abstract and keywords.	Reading of title, abstract and keywords.
Exclusion	Articles no containing Learning and Industry 4.0 in the keywords, title or abstract.	Articles no containing Learning and Industry 4.0 in the keywords, title or abstract.
Result	50 proceedings and articles.	
Reporting and dissemination (III)		
	Findings (Dimensions of Learning in Industry 4.0).	Findings (Dimensions of Learning in Industry 4.0).

Table 2 – Year of publication of documents

Year	Frequency	Percentage
2012	2	4%
2013	0	0%
2014	0	0%
2015	15	30%
2016	2	4%
2017	16	32%
2018	15	30%

Table 3 - Events or Journals from which publications were originated

Event or Journals	Frequency	Percentage
The 5th CIRP Conference on Learning Factories 2015	15	30%
The 8th CIRP Conference on Learning Factories 2018	14	28%
The 7th CIRP Conference on Learning Factories 2017	11	22%
The 6th CIRP Conference on Learning Factories 2016	2	4%
Manufacturing Engineering Society International Conference 2017 MESIC 2017	2	4%
27th International Conference on Flexible Automation and Intelligent Manufacturing FAIM2017	2	4%
International Conference on News Horizons in Education INTE 2012	1	2%
CIRP Annals - Manufacturing Technology	1	2%
45th CIRP Conference on Manufacturing Systems 2012	1	2%
2017 IMEKO TC1 TC7 TC13 Joint Symposium	1	2%

Table 4 – First Construct: Industry 4.0 Structure

Dimensions	*Keywords*
Management	*Factory Management. Works participation. Production Planning and Control. Lean Management. Logistics. Classification. Collaboration. Constructive Alignment. Context Recognition. Cost-efficient Qualification. Decent Work. Design. Factory Management. Interaction. Knowledge Exchange. Lean. Maturity Model. Middle Management. New Product Development. Optimization. Performance Management. Poka-Yoke. Shop floor top floor integration. Social innovation. Track and Trace. Works council. Works participation. Innovation center.*
Industry 4.0	*Classification. Industrie 4.0. Industry 4.0. Smart factory. Smart production. Smart products. Smart textiles.*
General Industry	*Changeable manufacturing systems. Closed loop material cycles. Digital business engineering. Empirical production research. Human-machine interaction. Human-machine-interface. Industrial engineering. Intelligent manufacturing. Lean management. Lean manufacturing systems. Lean manufacturing. Lean. Low cost automation. Machine level. Manufacturing engineering. Manufacturing systems. Mini-factory. Operating figures. Process optimization. Process planning. Product lifecycle management. Product planning. Production planning and control. Production planning and steering. Quality techniques of lean production. Scheduling.*

Table 5 – Second Construct: Technology Adoption

Dimensions	*Keywords*
Technology	*3d printing. Assistance systems. Augmented reality. Automation. Cyber-physical systems. CPS. Cyber-physical production systems. Digital transformation. Digital twin. Digitalization. Digitization. Internet of things. IoT. Raspberry pi. RFID.*
Application	*Context recognition. Debriefing. Digital and human centered decision support. Ergonomics. Industrial learning. Intelligent bin system. Learnstrument. Lightweight design. Machine learning. Model scale. Morphology. Multimedia. Object detection. Self-sufficient manufacturing system.*
Sustainability	*Sustainability. Sustainability in Manufacturing. Energy Efficiency. Effiziente Fabrik 4.0. Energy and resource efficiency. Energy-efficient Production.*

Table 6 – Third Construct: Learning Development

Dimension	*Keywords*
Interaction between industry and academia	*Experiential learning. Experimental factories. Industrial and university learning. Learning factories. Learning factory. Manufacturing education. Manufacturing research. Scenario based. Teaching factory.*
Education and Training	*Action orientation. Active learning. Blended learning. Collaborative learning. Constructivism. Didactic. Education. E-learning. Engineering education. Further education. Game-based learning. Hands-on education Human learning. Hybrid learning. Informal learning. Integrated teaching. Learning concepts. Learning environment. Learning objective taxonomy. Learning simulations. Problem-based learning. Project based learning. Reciprocal learning. Simulation. Situation aware learning. Social learning. Training. Training concept. Training development. Vocational training. Work-based learning.*
Competency and Skills	*Body of knowledge. Capability building. Competence development. Competencies. Competency. Competency development. Competency transformation. Digital skills. Future skill demand. Industry 4.0 skills. Interaction. Interdisciplinary research-groups. Socio-technical. Student skills.*

Table 7 – Research agenda for future studies: Learning Development

Questions and Research Directions	*Authors*
How to integrate educational content with the development of an energy efficiency infrastructure in industry?	*Kaluza et al., 2015 Kreitlein et al.,2015*
What is the impact of game-based learning on training students and practitioners in Industry 4.0 practices?	*Bohner et al., 2015*
How to promote a new teaching factory paradigm that includes a new business model that facilitates the two-way flow of knowledge exchange through a Teaching Factory Network in which there are multiple classrooms and multiple factories interconnected in remote learning and training channels?	*Rentzos et al., 2015*
How to apply a systemic approach to learning theory to teach lean manufacturing, automation technology, energy efficiency and process development in learning factories?	*Pittschellis, R., 2015 Schuhmacher et al.,2017*
How are university teachers bringing their effective application of digital skills in Industry 4.0 into their classrooms?	*Motyl et al., 2017*
What are the dimensions of a replicable guideline for the gradual implementation of a Learning Factory?	*Baena et al., 2017 Karre et al., 2017*
What are the needs of the industry of the future that can help in planning the content needed to develop employee training?	*Schallock et al., 2018*
How to promote collaboration in interdisciplinary research among educators, data scientists and cognitive psychologists in learning production and operation management in an integrated vision?	*Ansari et al., 2018*
What new research fields can be applied to Learning Factories?	*Oberc et al., 2018 Prinz et al., 2018*
What adjustments must be made in academic curricula given the new challenges of a changing industrial environment?	*Enke et al., 2018*
How to extend to new devices, in addition to desktops or laptops, the blended learning approach in university and industrial teaching environments, using various platforms, such as smartphones and tablets connected to the wireless network infrastructure, to promote learning inside and outside the industry?	*Rocha et al., 2018*
Future studies may seek more knowledge about the application of debriefing in industrial education associated with simulation processes, in particular in the context of teaching and learning.	*Tvenge and Ogorodnyk, 2018*
How to combine online learning and face-to-face training for production managers, production line leaders and production operators in developing	*Yang et al., 2018*

theoretical and practical training in the principles of Industry 4.0?

Table 8 – Research agenda for future studies: Industry 4.0 Structure

Questions and Research Directions	*Authors*
Future studies on manufacturing systems can address: Innovation and design of manufacturing systems, Models and enablers of product variety, New organization concepts for changeable manufacturing systems, Models and enablers for changeable production planning and control for changes in market demands, Concepts and solutions for process planning for product and system variants.	*Wagner et al., 2012*
How to integrate shop floor and top-floor processes in cloud-based services in small and micro-enterprises into a holistic view of learning?	*Faller and Feldmüller, 2015*
How to ensure the transfer of knowledge through the training of professionals from small and micro enterprises, especially through learning factories, at regional level?	*Wank et al., 2016*
How to offer product-service systems (PSS) with a holistic customer solution and not just the product or service offer, exclusively? With the implementation of the PSS, what changes will be needed in production-driven companies?	*Prinz et al., 2016*
How are small and medium businesses learning about Industry 4.0's new technologies and digital skills?	*Motyl et al., 2017* *Madsen and Møller, 2017* *Wienbruch et al.,2018*
How to overcome the hesitation to adopt the principles of Industry 4.0 due to implementation barriers such as the real financial benefit of new investments, as well as overcome the lack of specialized knowledge?	*Küsters et al., 2017*
How to promote Industrial Citizenship, i.e., the participation of people in decisions in industry, and the promotion of workers' social rights in facing the effects of digitizing production systems?	*Reuter et al., 2017*

Table 9 – Research agenda for future studies: Technology Adoption

Questions and Research Directions	*Authors*
How to qualify students and industry employees to apply the advantages of cyber-physical systems in production planning, control and monitoring?	*Seitz and Nyhuis, 2015*
How can students identify the technological resources available that are most appropriate in a particular production process and what should they be used for?	*Vila et al., 2017*
How to develop Learning Factories for institutions with reduced budgets, using equipment, hardware and simpler, but sufficient and representative, software to train employees and students for Industry 4.0?	*Abele et al., 2017*
How to develop computer science skills in production engineers through academic and industrial training given the industry digitizing trend in order to implement the best digital solutions to add value?	*Wiech et al., 2017*
Investigation must be expanded on the effects of Virtual Reality (VR), Augmented Reality (AR) or Mixed Reality (MR) on human factors, mainly studies on the critical factors of the use of wearables, fatigue effects and optical quality of the equipment	*Nunes et al., 2017*
The implementation of Industry 4.0 processes will change some professions due to automation. What will be the profile of the professionals who plan processes in industries?	*Trstenjak and Cosic, 2017*
How to develop a more economical and sustainable RFID system for use in a learning factory?	*Louw and Walker, 2018*

APPENDIX I

Scattering of unique Keywords indicated by the authors in their articles.

126 unique Keywords (alphabetic order)			
1	*3d printing*	64	*interaction*
2	*action orientation*	65	*interdisciplinary research-groups*
3	*active learning*	66	*internet of things*
4	*assistance systems*	67	*IoT*
5	*augmented reality*	68	*knowledge exchange*
6	*Automation*	69	*lean*
7	*body of knowledge*	70	*learn instrument*
8	*capability building*	71	*learning concepts*
9	*change enablers*	72	*learning environment*
10	*changeable manufacturing systems*	73	*learning objective taxonomy*
11	*Classification*	74	*learning simulations*
12	*closed loop material cycles*	75	*lightweight design*
13	*Collaboration*	76	*low cost automation*
14	*collaborative learning*	77	*machine learning*
15	*Competencies*	78	*machine level*
16	*Competency*	79	*manufacturing research*
17	*competency development*	80	*manufacturing systems*
18	*competency transformation*	81	*maturity model*
19	*composite material*	82	*middle management*
20	*constructive alignment*	83	*mini-factory*
21	*Constructivism*	84	*model scale*
22	*context recognition*	85	*morphology*
23	*cost-efficient qualification*	86	*multimedia*
24	*CPS*	87	*new product development*
25	*data management*	88	*object detection*
26	*debriefing*	89	*operating figures*
27	*decent work*	90	*optimization*
28	*decision support*	91	*performance management*
29	*design*	92	*poka-yoke*
30	*didactic*	93	*problem-based learning*
31	*digital and human centered decision support*	94	*process optimization*
32	*digital business engineering*	95	*process planning*
33	*digital skills*	96	*product lifecycle management*
34	*digital solutions*	97	*product planning*
35	*digital twin*	98	*production management*
36	*digitization*	99	*quality techniques of lean production*
37	*effiziente fabrik 4.0*	100	*questionnaire*
38	*empirical production research*	101	*raspberry pi*
39	*energy and resource efficiency*	102	*reciprocal learning*

40	*energy-efficient production*	103	*RFID*
41	*ergonomics*	104	*scenario based*
42	*error detection*	105	*scheduling*
43	*evaluation,*	106	*self-sufficient manufacturing system*
44	*evaluation tools*	107	*shop floor-top floor integration*
45	*experiential learning*	108	*simulation*
46	*experimental factories*	109	*situation aware learning*
47	*factory management*	110	*smart factory*
48	*further education*	111	*smart production*
49	*future skill demand*	112	*smart products*
50	*game-based learning*	113	*smart textiles*
51	*hands-on education*	114	*social innovation*
52	*human learning*	115	*social learning*
53	*human-machine interaction*	116	*socio-technical*
54	*human-machine-interface*	117	*student skills, sustainability*
55	*hybrid learning*	118	*sustainability in manufacturing*
56	*indirect sector*	119	*teaching factory*
57	*industrial engineering*	120	*track and trace*
58	*industrial learning*	121	*training concept*
59	*industry 4.0 skills*	122	*training development*
60	*informal learning*	123	*vocational training*
61	*innovation center*	124	*work-based learning*
62	*intelligent bin*	125	*works council*
63	*intelligent manufacturing*	126	*works participation*