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Abstract. The latest shift in the industry, known as industry 4.0, has introduced new challenges in manufacturing. The main characteristic of this transformation is digital technologies' effect on the way production processes occur. Due to the technological growth, knowledge and skills on manufacturing operations are becoming obsolete. Hence, the need for upskilling and reskilling individuals urges. In collaboration with other key entities, educational institutions are responsible for raising awareness and interest of young students to reach a qualified and equal workforce. Drawing on a thorough literature review focused on key empirical studies on learning factories and fundamental industry 4.0 concepts, trends, teaching approaches, and required skills, the goal of this paper is to provide a gateway to understand effective learning factories' approaches and a holistic understanding of the role of advanced and collaborative learning practices in the so-called education 4.0.

Keywords: Industry 4.0; Education 4.0; Smart Manufacturing; Learning Factories

1 Introduction

Considering the delivery mechanisms for learning and training in the Industry 4.0 (I4.0) paradigm, it is safe to say that traditional education is no longer fit-for-purpose. Virtual/Augmented Reality, Cyber-Physical Systems (CPS), Co-bots and 3D printing are just a few examples of technologies that are reshaping the way people think, learn, and work [1]. Many of today's students will work in new job types that do not yet exist, with an increased demand for leadership, resourcefulness and creativity. These are crucial skills considering the emerging production processes' demands.

Overall, the current education system follows a standard testing-oriented approach, which fails at measuring qualitative skills that are crucial in the upcoming years. Specifically, in the Smart Manufacturing paradigm, the gap between education and jobs is further widened by limited innovation in learning systems, which should be largely designed to mirror factory-style growth models. Education 4.0 (E4.0) [2–4] is a new learning approach that emerges from this urgent need for education systems to adapt in the I4.0 context. E4.0 is the desired approach to learning with the emerging Fourth Industrial Revolution, which focuses on the Internet of Things (IoT), Artificial

Intelligence (AI), Robotics, among other topics, all of which are already impacting our everyday lives. The main challenge of E4.0 is to prepare students for evolving industries, which means (a) a change on educational approaches must occur and (b) governments, educational institutions and employers should focus on job creation to tackle I4.0 challenges.

This paper provides a Literature Review (LR) regarding theoretical and methodological E4.0 approaches and innovative Learning Factories (LFs). The presented study tries to collect and analyse recent pedagogical strategies in LFs implemented with industrial partnerships, which were best suited to educate future factory engineers while identifying relevant learning skills.

Regarding the structure of the paper, the Introduction is followed by Section 2 that provides a detailed description and state-of-art of innovative LFs. Section 3 summarises the body of the review and draws important conclusions about the LFs and E4.0 topics while identifying gaps or inconsistencies in a body of knowledge. Finally, Section 4 concludes the paper, stating final remarks about the work presented and provides orientations for future work.

2 Innovative Learning Factories

This section consists of reviewing E4.0 approaches and LFs that demonstrate their relevance in supporting I4.0 applied research and education. This review's underlying research question is "*What is the best architecture of LFs to educate the next set of manufacturing engineers?*". The main goals are: 1) getting to know the main adopted teaching approaches when using LFs as a setting to learn; 2) understanding how a LF can establish a partnership and take advantage of it and finally; 3) identifying the most relevant skills to target to shape future engineers.

LFs are mainly present at universities and contribute significantly to the acquisition of a holistic understanding of I4.0 by creating a realistic setting in which academia, industry, and other entities can collaborate and validate the use of novel technologies. The LFs concept has been used worldwide and has proven to be a practical action-oriented approach where participants learn innovative factory procedures and their challenges in a production-technological learning environment [5].

Establishing interactions such as collaborations, partnerships, and integrations between university and I4.0 enterprises contributes to fostering students' employability rate, teacher's continuum learning and, consequently, stimulates regional growth [6]. On the one hand, E4.0 demands students to have skills capable of implementing and maintaining the latest technologies, which entails solving complex problems, being creative, taking quick and intelligent decisions, and analysing information. Often educational institutions lack friendly advanced equipment to provide an appropriate education to students [7]. On the other hand, enterprises need to respond to the globalisation challenges, delivering products and services at lower prices and better quality [6]. Moreover, Rocha Brito and Ciampi [6] stress that regardless of a country's political situation, governments must invest in Science and Technology to pursue socio-economic growth and development, which strongly supports collaborations. According to Karlik *et al.* [7], to be effective, these collaborations should have a considerable length in time, enabling the development of various fields such as science, education and the production industry.

Maia *et al*. [8] describe how two laboratories – one of Digital Manufacturing (DM) and the other of IoT - were developed at the Educational Foundation of Ignatius (FEI) University Center (Brazil) in partnership with two manufacturing companies, aiming to train engineering and computer science students to cope with IoT and I4.0 issues. The IoT laboratory resulted from the collaboration with an international telecommunication company, and its projects were focused on IoT applications, data analytics and hardware prototyping. The learning method used was *Problem-Based Learning*, which provided a challenge for the students to tackle and explore solutions. Additionally, students had a teacher to help find the materials and explain concepts, and tutor from the telecommunication company to help students develop a solution. Students who successfully solved the challenges were invited to work in scientific initiations. Moreover, these students also helped other students solve problems using a *Learning by Teaching* approach. For the implementation of the DM laboratory, two partnerships were established to support it: a DM software provider and an automation company. The first one provided access to 100 DM software licenses. The second one provided its experience in the implementation and offered a digital project of a robotic cell and its physical construction. As a result of the collaboration between these two labs, new problems regarding Machine-to-Machine (M2M) communication emerged, involving societal and business entities in academic research. Besides the evident benefits this active learning environment offered to students, this experience was also significant to enhance each manufacturing companies' particular expertise.

Oberc *et al.* [9] established a LF training on integrating collaborative robots into manual assembly lines through an *Action-Oriented* and *Problem-solving approach* in the LF of the Chair of Production Systems (LPS) at the Ruhr-University in Bochum. This training focused on organizational and personnel topics. Authors defend that this was made possible by the collaboration between academic institutions and industrial companies or academies, which revealed its utility, for example, in the implementation phase. Students could develop code for robots provided by various enterprises. Apart from this, the LPS is involved in research activities related to the Human-Robot Collaboration (HRC) planning and simulation environment, contributing to functional integration of a robot simulation and programming framework in *Ema* [10]. From this perspective, partnerships for research purposes seem to be very feasible and desirable.

Schuh *et al.* [11] work consisted of an empirical *Work-based* approach to understand how learning in production is supported while reducing its complexity at the same time. It took 30 working days to test the integrity of certain assumptions concerning new HRC interfaces for the provision and permanently updated Digital Twin information for work instructions. The survey was conducted by the Laboratory for Machine Tools and Production Engineers at the Demonstration Factory of the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen Campus. This simple collaboration inside the university allowed the learning content to be immediately linked with the needs and applications of daily work practically and economically. The research was supported by the German Federal Ministry of Education and Research within the collaborative research project *ELIAS* [12]. The authors seek to permanently develop solutions in the future concerning automation for the context-sensitive provision and customized instruction.

The *AutFab*, located at the University of Applied Sciences Darmstadt (h_da) [13], is a fully automated I4.0 LF used for education, research and development purposes. It consists of high bay storage, two assembly and two inspection stations. Students of different courses are educated here, whether by working in labs or directly in the *Autfab*. The *Problem-Based Learning* approach consists of establishing the communication between the software system MATLAB/Simulink and the *AutFab* via OPC and analysing the data they get, or directly in the *Autfab*, focusing on project planning and managing as well as on the presentation and documentation. The constant evaluation of the *AutFab* projects constitute a benefit for students, researchers and different industries involved. On the one hand, students highlight the hands-on relevance for their future work. Usually, students' thesis at h_da are conducted in industry, and often supervisors positively report the students' practical skills. On the other hand, researchers and companies who provide conditions for the undergoing thesis benefit from discoveries and a qualified workforce. This alliance has revealed that *Project-based learning* in the *AutFab* has a crucial effect on students' education. Besides this, *AutFab* usually collaborates with high schools to present them the LF and thus attract new students. Authors mention that working in multidisciplinary teams and contacting suppliers improves students' communication skills and allows teachers to broaden their knowledge continuously.

The *Industry 4.0 Pilot Factory* (I40PF) [14], based in Austria, emphasizes the importance of cooperation with different industries, i.e., machinery and equipment. I40PF provides easy access to I4.0 infrastructures for Small and Medium Enterprises (SMEs), whereas key industrial technology suppliers help build a factory that meets I4.0 requirements. Kemény *et al.* [15] foresee a possible partnership between the I4.0 LF at TU Wien and the premises of MTA SZTAKI in Gyor and Budapest. The authors provide a high-level description of the possibilities of such a partnership by describing the underlying features and types of collaboration to complement capacities. From the authors perspective, cooperation is more advantageous by involving different product life cycles, namely design, procurement, testing prototypes and production. This interconnection between different LFs may create an exciting and productive baseline for research and learning while it provides a meaningful complement to the students' curricula.

Ogorodnyk *et al.* [16] installed a roller skis assembly line in the faculty NTNU in Norway to teach practical skills and theoretical knowledge on waste reduction and push/pull production systems. However, it was built with no technological appliances. Although the authors defend that the activity was able to respond to its main goal, enhancing theoretical and practical knowledge while working on a "real assembly line", students could probably take more advantage of it if some collaboration with a real industry was made, resembling it to an actual production assembly line. Other projects involve *Problem-Based Learning* approach and students at lower levels of studies [17, 18]. However, hitherto, there is no evidence of collaborations such as the ones mentioned previously. Smit *et al.* [19] advocate that Industry-School Partnerships (ISP) foster students' interest in STEM careers, and it is highlighted later in this paper the gender gap persisting in this field. According to PORDATA [20], in Portugal, only 24% of students attending higher education in engineering, manufacturing and construction are female. And this gap is visible both in education and the workforce [21]. Furthermore, Watters *et al.* [22] stress that despite the challenges and threats (i.e., financial, quality teacher access and ISP model) involved when establishing a partnership, it provides meaningful and authentic learning for students environment. Table 1 sums up the studies mentioned in this review (excluding the ones that did not yet take actual place), identifying the core teaching approaches, type of collaboration, and targets.

Table 1. Projects' characteristics

		Maia *et al.* [8]	Oberc *et al.* [9]	Schuh *et al.* [11]	Simons *et al.* [13]	Ogorodnyk *et al.* [16]
Approach	Problem-Based Learning	✓	✓		✓	
	Project-Based Learning	✓			✓	✓
	Learning by Teaching	✓				
	Action-oriented	✓	✓		✓	✓
	Work-based			✓		
Collaboration type	Inside institution	✓		✓	✓	
	Outside institution	✓	✓		✓	
Target	University students	✓			✓	
	High school students or lower				✓	✓
	Operators			✓		

3 Discussion

I4.0 envisions a future where small distributed and digitalized production networks operate autonomously in factories. As a result, they will be able to plan production in response to any change properly. Meanwhile, I4.0 researchers and technology developers still have a long way ahead. LFs contribute significantly to understanding the primary enablers and barriers of the Smart Manufacturing vision since they are commonly used for learning and research purposes. Thus, most of the time, it requires developing and testing models and technologies, new manufacturing processes, interaction, and decision support systems [14]. All of these requirements can be more easily achieved through the establishment of collaboration networks. Collaborative networking between industry and academia allows students to improve their project planning competencies and solve complex problems, which enriches their comprehensive understanding of CPS [8, 9, 11, 13]. In some cases, it also improves students' presentation and documentation skills [13]. Besides that, teachers' knowledge is also enhanced, which can be positively integrated into their courses. Nonetheless, we highlight the importance of long-term collaborations since these are also long-term developments that require extensive investigation. Funded research is also fundamental. More research means more break-throws and advancements, which means better education, a more qualified workforce, and social and economic development. For enterprises, it constitutes an opportunity to develop their knowledge and be able to produce better products.

Concerning teaching approaches, it looks like there has been a steady trend toward Student-Centered learning, such as *Problem* and *Project-Based learning*, aiming to respond to the new challenges. Educational organizations must redefine the required profiles and skills requirements and change their instructional notions based on the idea that I4.0 demands interdisciplinarity [8], communication and analytical skills, and creativity, among others [23]. Tutoring was also something that we retained as a good practice for LF contexts. Students take part in a continuous learning and cooperative process of creating and restructuring knowledge.

Inferring from this review, LFs are mainly implemented at universities to train graduate and undergraduate students. However, one should also consider involving lower levels of studies, motivating young pupils to consider a career in manufacturing and, this way, guarantee a future qualified workforce. A complex modular CPS coupled with a *Problem-Based Learning* approach (prominent in this LR), interdisciplinary teams and tutoring seem to be the key to provide the skills and substantial knowledge of I4.0 concepts to the next set of manufacturing engineers (see Fig. 1). A step forward is to consider a collaboration with a related LF, making its technologies more advanced and accurate to the real smart factory environments. It is expected that it increases the system complexity and thus generates a holistic understanding of I4.0. The latest is halfway there to motivate students to follow a career in engineering.

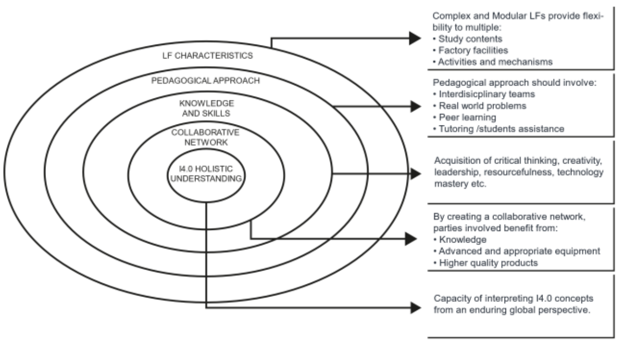

Fig. 1. The Architecture of an effective LF

4 Conclusion

In this paper, we presented a LR regarding theoretical and methodological E4.0 approaches and innovative LFs. We collected and critically analyzed recent pedagogical approaches in LFs implemented with industrial partnerships while identifying relevant learning skills to be tackled in the current I4.0 educational context.

From the review, we conclude that the road map for an I4.0 holistic understanding combines specific LF characteristics, approaches, processes and skills (see Fig. 1). Together, these "blocks" may constitute the key axes to an effective LF architecture, capable of endowing students with the required I4.0 skills and knowledge to succeed. It is expected that by testing such architecture and analysing the most effective ways of connecting the mentioned "blocks", a gateway to further explore and understand learning factories' approaches and the role of advanced and collaborative learning practices, arises.

Regarding future work, we intend to hold an activity in a set of Portuguese schools, in which students are orientated to build a small LF, consisting of a 3D printable production line that uses CPPS related technologies. In this context, we aim to address and validate the collaborative network approach in which the involved schools and targeted related companies can mutually take advantage of it.

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