Lean Learning Factories: Concepts from the Past Updated to the Future

Gabriela R. Witeck(✉) and Anabela C. Alves(✉)

Centro ALGORITMI, Department of Production and Systems,
University of Minho, Guimarães, Portugal
anabela@dps.uminho.pt

Abstract. Lean Production has its roots in the Toyota Production System, introduced before World War II, and is constantly evolving. Its importance as an organizational management model triggers the need to teach it in the academy. Promptly, Lean Education is being taught all over the world. However, teaching Lean using traditional expositive lectures is not effective, and many academics and practitioners are using active learning methodologies. Lean and Learning Factories, which are two concepts that come from the past, are more than alive nowadays. This paper presents a literature review regarding Lean Learning Factories, based on a scientific articles research at Scopus database. The review was conducted for the period from 1990 to 2021 and resulted in a total of 76 papers. Main findings revealed that the first articles within the context of Lean Learning Factories were published in 2006. The learning factories initiatives were developed by universities and the most used learning strategies are simulations and gamification. Also, the latest configurations of these are in Germany, Austria, and Croatia. The results revealed an increase in the number of publications since 2015, reaching 14 publications in 2020.

Keywords: Lean thinking · Learning factories · Gamification · Industry 4.0

1 Introduction

The engineering workforce of the future is being prepared in Higher Education Institutions (HEI). Nevertheless, changes in engineering education are often slow [1], being teacher-centered education, using for example, traditional expositive lectures in a classroom, the most adopted instructional method. Fortunately, new and different instructional methods associated with learning simulation environments, or even, real environments, through partnerships with industry companies and organizations, are also being used in HEI [2–5]. Particularly, for future engineers to visualize and understand their role in the workplace, make sense learn in different environments. That is the reason for "Learning Factories" gaining much attention.

In a "Learning Factory" environment, students/trainees/employees are involved with authentic processes. To promote this involvement, it is established a physical mockup that resembling a production system with a real value chain. Therefore, a physical product is manufactured and a didactic concept that comprises formal, informal, and non-formal learning is learned [6].

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The idea of "Learning Factory" was originated in the decade of '90s, when the National Science Foundation (NSF) sponsored a grant to a consortium led by Penn State University to design a learning environment that would promote engineering design projects with industry [7]. These projects integrated students from Industrial, Mechanical, Electrical, Chemical Engineering and Business, also involved 43 faculty members, across five time zones [8]. Later, the National Academy of Engineering reward Learning Factories achievements with the Bernard M. Gordon Prize for Innovation in Engineering and Technology Education [9].

Nevertheless, others authors, namely Foden [10] and Gento et al. [11] pointed out the origin of the concept to the beginning of the last century (1916) by the hands of Herbert Schofield and Loughborough College. At that time, it was named "instructional factory", as the main aim was to instruct workers [10]. "Training on production" was considered an instructional quick and important method for, particularly, emergent situations as was the First World War and Second World War. In the latter, it was adopted on a large scale under the name of "Training Within Industry" [12, 13]. Learning by doing is a key concept under the instructional method. Before and now, it remain preferred method of teaching, mainly when anyone is being prepared for practical and productive work for society [14].

The concept of Learning Factories rises more interesting since the Fourth Industrial Revolution leaps forward and hence labeled Industry 4.0 [15]. As a company converges from traditional automation to a fully connected and flexible system, including information and operations technology. The result is a production system more efficient, with a greater ability to predict and adjust to changes.

However, as all industry processes come from human assets, people are expected to be the key to the process, eliminating wastes (i.e., activities that do not add value to the products in the point of view of the client) that exist in these processes [16]. This concept of "waste", the contrary to the "value", is key to a Lean organization that recognizes people as the most important asset of companies [17–19]. People's behavior can lead to culture organizational and affect, negative or positively, the company's success. More than an organizational model, Lean Thinking [20, 21] is a culture that is not easily understood, even by academics [22]. This contributes to the difficulty to implement Lean [23–26]. The way to success is the symbiosis of people and technology along the entire value creation chain.

In a Lean Learning Factory, people can see with "their own eyes" and make mistakes until they learn, promoting continuous improvement. The learning model from real factories operates next to the industry and provides a dynamic education and assay environment. The combination of Lean learning and other instructional methods such as gamification can provide new and important competencies to professionals once that allow students/trainees/workers to develop such competencies by solving problems and making decisions [27–30]. When it happens, Lean learning becomes effective [31–33] and brings many benefits that impact professionals and personal lives [34–39].

As well, it allows exploring aspects related to the teaching-learning process through interactive and collaborative methods to expand the company's knowledge. It signifies the opportunity to generate greater value within the four walls of the company, and requires suiting the schooling process and evolves education programs within factories.

Interest in Learning Factories is growing. In 2012, Wagner et al. [40] identified more than 25 research and development organizations that have established learning factories. In 2018, almost 30 learning factories were founded in Germany [41]. Abele et al. [30] identified more than 60 learning factories, almost all from the last decade, many related to Lean, others with Industry 4.0, and some related to both concepts.

This paper presents a literature review on Lean Learning Factories to show that these two concepts with different origins in time and fields (industry and academic) are combined to conveniently instruct engineering students in a simulated learning environment. This literature review was based on a scientific articles research at Scopus database. The review was conducted for the period 1990 to 2021. This period was chosen due to this designation is in use for the first time by Penn State University.

The paper structure consists of four sections. The first section is the introduction, where the objectives of this paper are introduced, and a brief contextualization is illustrated. Materials and methods are composed in section two. The third section presents the results of the literature review. Lastly, the fourth section outlines concluding remarks.

2 Materials and Methods

In this research, the authors developed a literature review in the Scopus database in the period 1990 to 2021. The question and sub-questions that guided this research were:

- "Is the Learning Factory used as an instructional method to teach Lean?
  - "Which countries are using this method of teaching Lean?"
  - "Is the Learning Factory promoted/funded by a company?
  - "What learning strategies are being used?"

The string used was "Lean" AND "Learning factory". These were searched in title, abstract, and keywords for the period from 1990 to the present. Figure 1 presents the number of papers obtained.

Fig. 1. Number of papers obtained from Scopus search.

3 Results and Discussion

This section presents the results in terms of quantitative statistics and answers to the sub-questions, namely, countries/universities, companies involved and learning strategies used.

3.1 Quantitative Statistics

Seventy-six papers were evidenced with "Lean" and "Learning factory" in the title, abstract and keywords, and 70% of which were published in conferences. Related to the question raised in Sect. 2, it was answered by this result, as the papers, indeed, discussed Learning Factory as an instructional method/learning methodology suitable for teaching Lean.

For the quantitative analysis, the authors used the Scopus functionality "Analyse research results" and the graphics generated by it. Three main graphs were collected: number of documents by year, number of documents by country, and learning strategies used in the learning factories.

Figure 2 shows the number of documents per year. It is possible to realize the growing interest in Lean Learning Factories what corroborates the importance of these two concepts, even currently, as mentioned in the title of this paper. In the last year, 14 papers were indexed in the Scopus database.

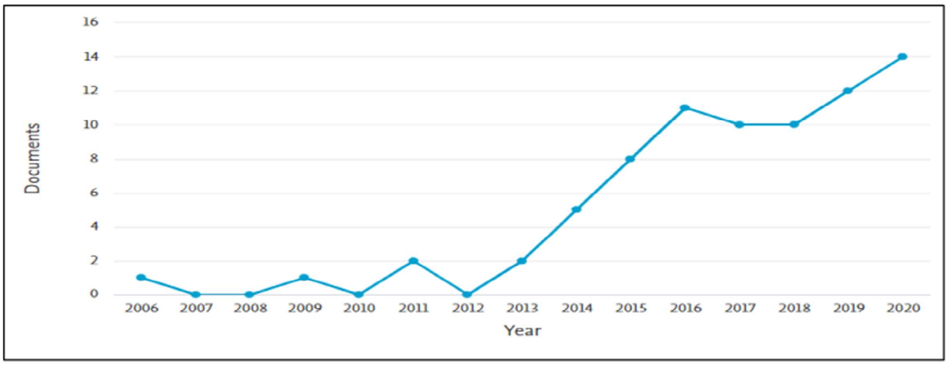

Fig. 2. Number of documents by year.

In total, 30 universities were identified associated with Learning Factories, which aim to teach the fundamentals of concepts related to Industry 4.0 and promote the student's development of Lean competencies and skills.

To answer the first sub-question (country/university), Germany is the country with more papers published, as the Fig. 3 reveals.

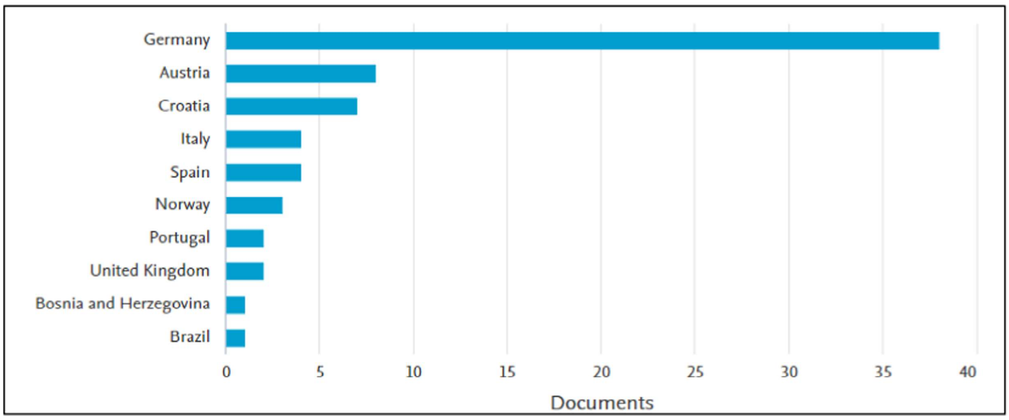

Fig. 3. Number of documents by country.

3.2 Companies Involved and Learning Strategies

To answer the second and third sub-questions raised in Sect. 2, namely, companies involved and learning strategies, the authors analyzed the content of full papers. This analysis allowed to discard eleven papers because nine did not have the full paper and authors could not read their content. Two papers were not related to the Lean organizational model. After applying these exclusion criteria (represented in Fig. 4), it resulted in 65 papers.

Fig. 4. Number of papers obtained after exclusion criteria.

Each paper was carefully read and some information about it was collected. This information was placed in a spreadsheet file. The information was related to the sub-questions: companies associated and learning strategies.

Regarding the sixty-five papers about Learning Factory context to teach Lean Thinking, many and diverse learning strategies are being used for Lean learning. Simulation of the industrial environment is most cited. The detailed analysis of the papers revealed the learning strategies resulted in Fig. 5.

For example, the Simulation learning strategy was used by the authors Crnjac et al. [42] during the development period of a new product, in a Lean Learning Factory. This passive strategy could help to visualize how the new product will "behave" in its environment under the influence of different environmental factors. Then, the students could learn about waste reductions in cost and quality. Moreover, Fu [43] related the logistics simulation teaching remains at the simulation level with a certain gap between real logistics production practice.

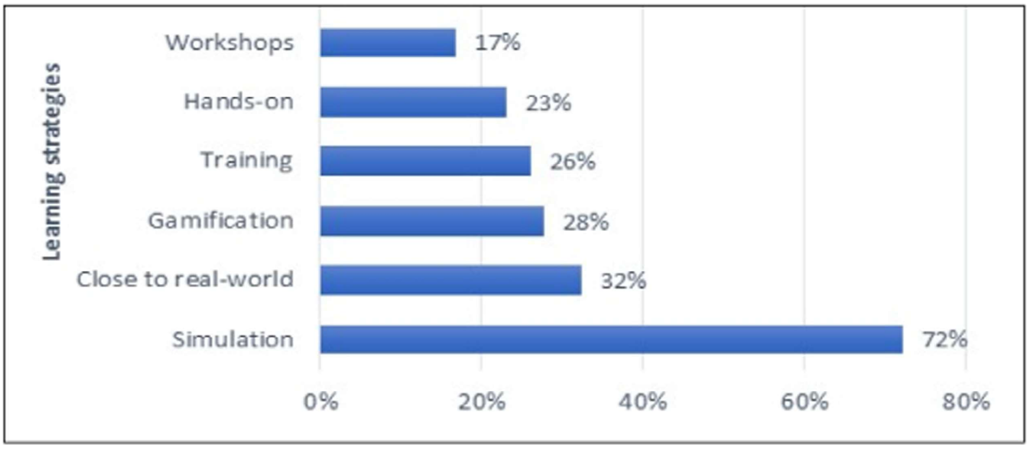

Fig. 5. Percentage of learning strategies used in the learning factories

3.3 Discussion

This discussion intends to highlight some aspects derived from the results. First of all, a growing interest in the Learning Factory as an instructional method, not only for teaching Lean but also other concepts such as the ones related to Industry 4.0. Many authors could say that this is a fact well known but if this is the case why not more universities are investing in it? Probably because of the high investment that is needed. For more details about the investment it could be seen the book from Abele et al. [30]. It seems Germany is the leading country in this investment; at least, more papers were published by this country. The reason for this may lie in the fact that in 2011 the Initiative on Learning Factories was founded in Darmstadt, Germany, as a union of several European Learning Factories. In the same year, the 1st Learning Factories Conference was launched in the same city. Since then, every year this initiative, which has been renamed the International Association of Learning Factories, has organized this conference, now in the 11th edition.

Additionally, in 2014, the International Academy for Production Engineering (CIRP) started a Collaborative Working Group (CWG) on the topic ‘Learning Factories’. In this CIRP CWG, the main characteristics of the learning factories are defined for the dimensions of product, process, didactics, setting, and purpose [27].

Therefore, it is not surprising that most papers come from Procedia CIRP and Procedia Manufacturing (87%). Unexpectedly, countries like the US, that which has a long tradition of implementing Learning Factories, did not appear in the result of this literature review.

Regarding the 65 papers, all initiatives are from universities and institutes. Some of these initiatives were supported by national and/or international projects. The research showed few connections to companies/industries (only in 15 papers).

Despite active learning methods (e.g., close to real-world experience; gamification; hands-on or workshops) being recognized as a superior approach of instruction in Lean, a major of articles afford that the learning factories instructors still use passive learning methods (e.g., traditional computer simulations and training). Learning activities, or experiential learning, provide students’ response to being actively engaged with the task. But, in the case of courses/programs related to Lean, it is difficult to teach /apply in a classroom environment [31], for this reason, the involvement between academia and industry is so important.

This section discussed and provided the answers to the questions that guided this research. Learning Factories are, in fact, serving to teach Lean concepts. More recently, such contents implied Industry 4.0 technologies and how Lean practices benefited from them.

4 Conclusion

This paper presented a literature review related to Lean Learning Factories. These concepts are not new, but this fact does not inhibit the growing interest in them. Lean Thinking is, in fact, a difficult content to teach because it is more than a content [32, 41], it is a competency needed to be developed. The concept of Learning factories has a long history, keeping an appropriate learning environment that explores the approaches and everything that instructors need, as this research reveals.

This research illustrated 76 papers from the Scopus database, which Learning Factories settled all over the world and associated with universities and/or companies that funded it. As findings of this research could be identified that many learning strategies are being applied in the context of the Learning Factory to teach Lean Thinking.

To effectively achieve the Lean learning strategies such simulation and gamification are the preferred approaches reported in the literature as effective teaching approaches. Furthermore, the research showed few connections to companies/industries, this fact may be associated with the systemic innovation learning is still in the process of being present in companies.

Limitations of this study are associated to the unique database research and the keywords. It is preliminary research, and much more could be done in future work, namely, obtaining the outcomes achieved by these Lean Learning Factories.

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