Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 45 (2020) 84–89

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

10th Conference on Learning Factories, CLF2020

A science mapping study on learning factories research

Pablo Martinez[a], Adriana Vargas-Martinez[b], Armando Roman-Flores[b], Rafiq Ahmad[c,*]

[a] *Department of Civil and Environmental Engineering, University of Alberta, Edmonton, T6G 2R3, Alberta, Canada*
[b] *Department of Mechatronics and Electrical Engineering, Instituto Tecnologico y de Estudios Superiores de Monterrey, Monterrey, Nuevo Leon, Mexico*
[c] *Laboratory of Intelligent Manufacturing, Design, and Automation (LIMDA), Department of Mechanical Engineering, University of Alberta, Edmonton, T6G 2R3, Alberta, Canada*

Abstract

Learning factories are a rising and promising environment for engineering education, training, and research. Practical interest in learning factories has peaked in recent years, attracting the worldwide attention of scholars and practitioners. This study conducts a scientometric review of the global research published since 1995 on learning factories, through co-citation, keyword and clustering analysis. A total of 367 journal papers and conference proceedings from the Scopus database were analyzed, to distinguish key publications and main research trends. By performing a mapping exercise, a detailed analysis of the learning factories' literature enables academic support for future research. The provided results are used to identify the main areas of contribution of learning factories research and understand the potential gaps in current research.

Keywords: learning factories; manufacturing research; scientometric analysis; review

1. Introduction

Learning factories have been an academic approach to bridge the gap between advanced manufacturing technologies, engineering teaching methods, and the labor market. Challenged by rapid changes in manufacturing

* Corresponding author. Tel.: + 1-780-492-7180.
E-mail address: rafiq.ahmad@ualberta.ca

10.1016/j.promfg.2020.04.072

techniques, academic and industry professionals are brought together to collaborate towards an improved educational environment. By enhancing learning and teaching productivity, learning factories contribute to the advancement and innovation of learning techniques, while keeping a high level of industrial integration [1]. To provide a deep understanding of the intellectual core of the learning factories domains in teaching, manufacturing, and industry, this paper proposes a science mapping analysis of the learning factories literature since 1995. In pursuing this line of inquiry, the areas and topics researchers have focused on can be unveiled, as well as potential gaps that limit potential future research.

2. Research methodology

The scientometric analysis is considered as a technique that measures research impact and citation processes to map the current knowledge and its evolution of a field based on large academic datasets [2]. Although a manual review of research fields provides an insightful and detailed overview, it remains prone to bias and is limited in terms of subjective interpretation. Therefore, the current study proposes a holistic analysis of research around learning factories using the scientometric approach, a research method to ease visualization and mapping of knowledge domains [3]. Visualizing the entire field of learning factories' research will enable readers to gain a comprehensive perspective of research patterns and trends in the field. The methodology for this current mapping study will be explained below and its overview can be found in Fig. 1.

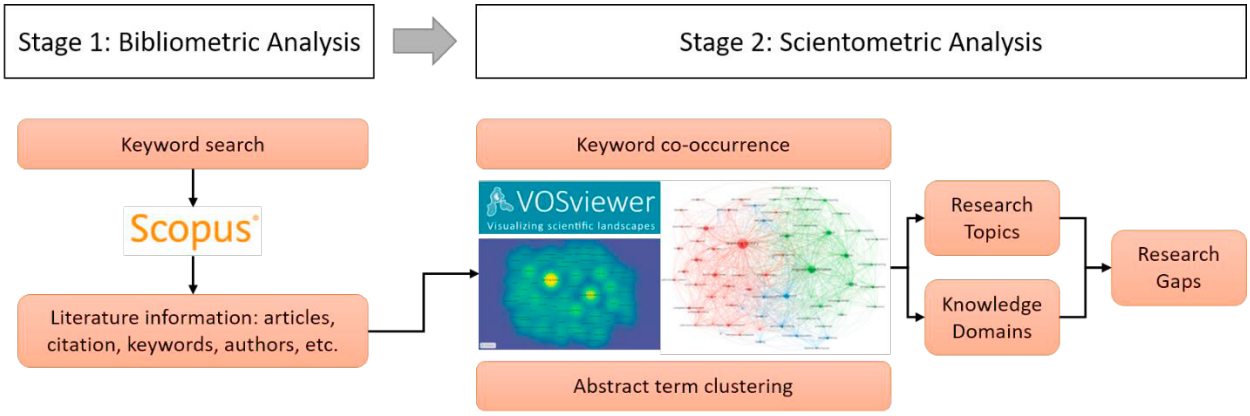


Fig. 1. Overview of the proposed research methodology.

Data acquisition of existing literature is crucial in this research since it determines the scientific publications from which any conclusions will be drawn. For this study, the Scopus database is used as the literature source due to the wide range of coverage in the research domain of learning factories [4]. The existing literature related to learning factories in the selected database is then retrieved by using a keyword search. According to the objective of this review, the selected keywords are "learning factories*" OR "teaching factories*" (note that the wildcard character * is used to capture variations of one keyword). Finally, the search yielded 367 results, namely 267 conference proceedings and 100 journal articles. Keyword analysis and abstract term cluster analysis are the methodologies used in this study to reveal research patterns. These techniques have been recommended to ease visualization and posterior interpretation of the mapping results in previous studies [5,6].

3. Mapping results

3.1. Sampled literature overview

The keyword strategies mentioned in Section 2.2 were employed to identify relevant academic articles in journals and conference proceedings. The top 10 by the amount of publications in the field have been summarized in the

table in Fig. 2. A majority (56.95%) of academic publications on learning factories are found in two conference proceedings: *Procedia Manufacturing* and *Procedia CIRP*. The remaining publications are divided between 54 different journals or conference proceedings. Barring a few exceptions, most journals or conference proceedings contain one or two publications on the field. Fig. 2 shows how the number of publications, in either journal or conference proceedings, on the research topic under review has varied each year. Publications on learning factories between 1995 and 2012 remained below 10 publications per year. However, academic contributions have spiked since then, reaching 79 publications by the end of 2019.

Journal or Conference Title	Number of Publications	% Total Publications
Procedia Manufacturing	133	36.24%
Procedia CIRP	76	20.71%
IOP Conference Series Material Science and Engineering	8	2.18%
Proceedings Frontiers in Education Conference	6	1.63%
IFIP Advances in Information and Communication Technology	4	1.09%
International Journal of Engineering Education	4	1.09%
Productivity Management	4	1.09%
Advances in Intelligent Systems and Computing	3	0.82%
Journal of European Industrial Training	2	0.55%
Journal of Engineering Education	2	0.55%

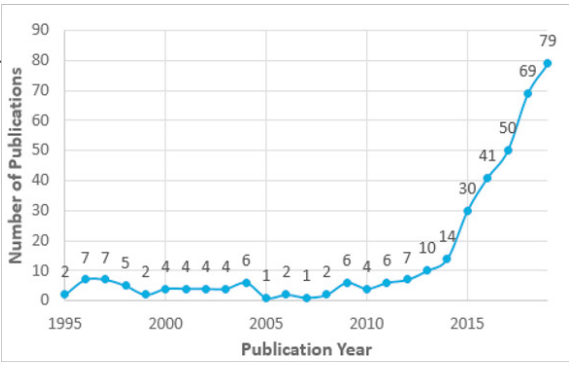
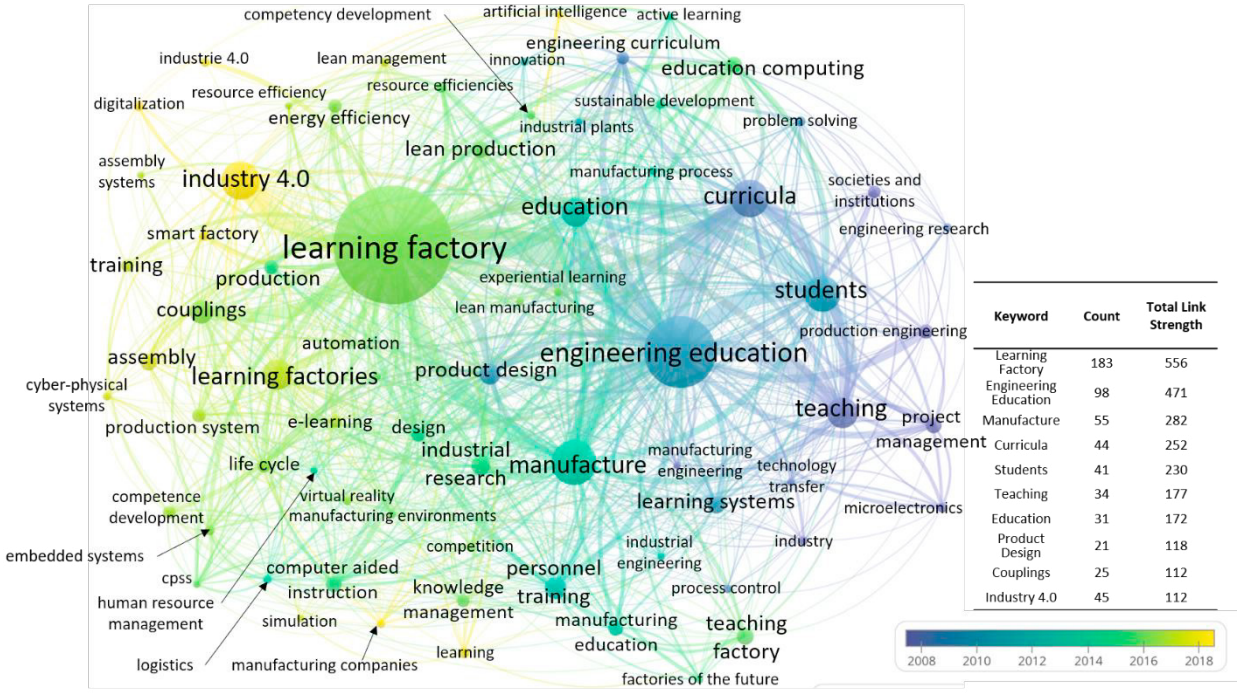


Fig. 2. Overview of published studies in learning factories (period 1995-2019). Left: List of the top 10 journals or conference proceedings. Right: Historical trend of published studies.



Keyword	Count	Total Link Strength
Learning Factory	183	556
Engineering Education	98	471
Manufacture	55	282
Curricula	44	252
Students	41	230
Teaching	34	177
Education	31	172
Product Design	21	118
Couplings	25	112
Industry 4.0	45	112

Fig. 3. The network of co-occurring keywords timeline related to learning factories research.

3.2. Keyword co-occurrence network

Keywords represent the core content of the published documents and showcase the range of areas researched within the boundaries of any knowledge domain [7]. The visualization of the keyword network is chosen to demonstrate the results of the bibliometric analysis of the literature; thus, keyword co-occurrence mapping of the research field is obtained using VOSviewer. The output of the VOSviewer software is a distance-based map in which distance represents the strength of the relation between two keywords [8]. A more significant distance usually indicates a weaker relationship between two labels or entities, and the label size is directly proportional to the number of publications in which the keyword is used by the authors [7]. To obtain a relevant and clear keyword map, the minimum number of occurrences is set to 6 so that 70 out of 1774 keywords meet the threshold. This threshold selection is based on multiple experiments to generate optimal clusters. Fig. 3 shows the resulting network of co-occurring keywords with 937 links and a total link strength of 2555, and a table summarizing the keyword occurrences and each entity node strength.

3.3. Abstract term clustering

Document co-citation analysis enables understanding intellectual structures in a specific research field and demonstrates the quantity and authority of references cited in publications. In this section, a network of document co-citation is generated, using CiteSpace [9], to represent the relationship between citations at an individual level. Then, the obtained map is used to cluster documents by abstract terms. A network with 267 nodes and 827 links is presented in Fig. 4. Each node represents a publication and its label shows the first author's name and the publication year. Each link represents the co-citation relationship between the corresponding publications. The co-citation frequency between documents is represented by the node size.

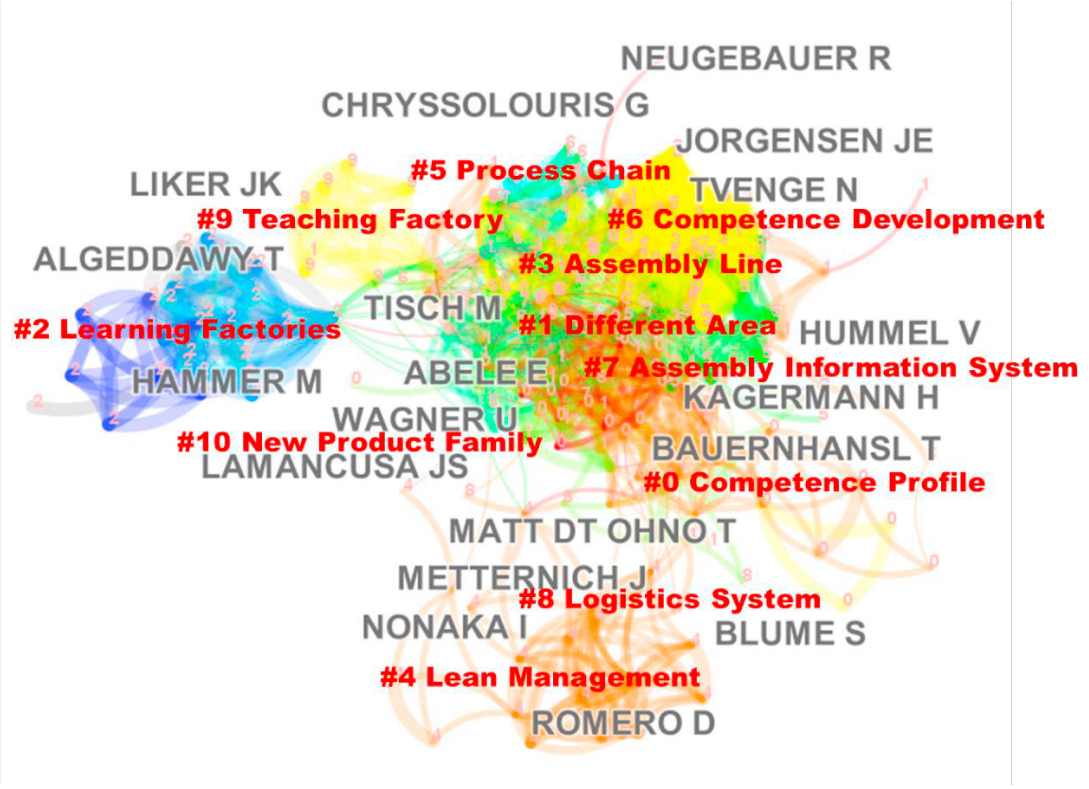


Fig. 4. Network of document co-citations with abstract term clustering.

A total of 11 clusters were identified based on the abstract of each of the documents cited in each cluster. Each cluster is represented by a general label, and the documents of each cluster are showcased in different colors. Table 1 summarizes the relevant cluster information. Some alternative labels are shown based on well-known semantic algorithms, namely the latent semantic indexing (LSI), the log-likelihood ratio (LLR), and the mutual information (MI) algorithms [9]. Then, the most representative publications for each cluster are identified [10].

Table 1. Document co-citation cluster information of learning factories research since 1995.

Cluster ID	Size	Abstract Term Label	Alternative Labels (LSI, LLR, MI)	Representative Documents
0	33	Competence Profile	Experience-based Knowledge, Learning Objectives	Abele, E. et al. [1], Enke, J. et al. [11]
1	30	Different Area	Logistics Processes, Application-specific Need, Economic Evaluation	Erol, S. et al. [12], Kreimeier, D. et al. [13]
2	29	Learning Factories	Information Technology, Education Method, Engineering Program	Ssemakula, M.E. et al. [14], Morell, L. et al. [15]
3	25	Assembly Line	Energy-efficient Production, Workforce, Material Flow System	Abele, E. et al. [1], Lang, S. et al. [16]
4	24	Lean Management	Assistant System, Robot Integration, Activity Analysis	Seitz, K.F. et al. [17], Thiede, S. et al. [18]
5	24	Process Chain	Innovation Transfer, Systematic Method, Space Restriction	Abele, E. et al. [19], Erol, S. et al. [12]
6	22	Competence Development	Assembly System, Product, Advanced Education	Kemény, Z et al. [20], Mourtzis, D. et al. [21]
7	20	Assembly Information System	Automation, Learning Context, Institutional Learning	Mattson, S. et al. [22], Blume, S. et al. [23]
8	17	Logistics System	Experience-based Knowledge, Production, Specific Competence	Prinz, C. et al. [24]
9	10	Teaching Factory	Industrial Learning, Experience-based Knowledge, Learning Factory	Mavrikios, D. et al. [25], Chryssolouris, G. et al. [26]
10	7	New Product Family	Changeable Manufacturing System, Production Volume	ElMaraghy, H. et al. [27]

4. Conclusions and future work

Learning factories have started to transform educational and training paradigms and have attracted increasing attention from researchers and practitioners alike. A scientometric study is performed to explore the status and current trends of the related research, analyzing 367 documents published since 1995. In summary, research in the learning factories has been exhaustive in the three main areas related to it: education, manufacturing, and system design and development. The study performed shows that current researchers have switched the focus from the educational discussion around the correct teaching approaches and methods to the development of advanced learning factories around Industry 4.0 principles, virtual environments, and artificial intelligence (see Fig. 3). Furthermore, current research trends and the most relevant publications in the field have been identified. From energy efficiency analysis in assembly lines to the development of lean management tools to integrate robotic platforms in manufacturing processes, learning factories have proven to be a great resource for researchers in multiple areas.

Despite the contributions offered in this study, the findings are to be considered in light of certain limitations. As discussed, the findings are based on the initial selection of keywords and certainly may limit the coverage of the current literature. In addition, delving into the aspects of ‘why’ and ‘how’ research has been conducted so far in this field remains beyond the scope of this study, and will be addressed by the authors in future work.

References

[1] Abele E, Chryssolouris G, Sihn W, Metternich J, ElMaraghy H, Seliger G, et al. Learning factories for future oriented research and education in manufacturing. CIRP Annals 2017;66:803–26. doi:10.1016/j.cirp.2017.05.005.

[2] Mingers J, Leydesdorff L. A review of theory and practice in scientometrics. European Journal of Operational Research 2015;246:1–19. doi:10.1016/j.ejor.2015.04.002.

[3] Börner K, Chen C, Boyack KW. Visualizing knowledge domains. Annual Review of Information Science and Technology 2005;37:179–255. doi:10.1002/aris.1440370106.

[4] Mongeon P, Paul-Hus A. The journal coverage of Web of Science and Scopus: a comparative analysis. Scientometrics 2016;106:213–28. doi:10.1007/s11192-015-1765-5.

[5] Cobo MJ, López-Herrera AG, Herrera-Viedma E, Herrera F. Science mapping software tools: Review, analysis, and cooperative study among tools. Journal of the American Society for Information Science and Technology 2011;62:1382–402. doi:10.1002/asi.21525.

[6] Martinez P, Al-Hussein M, Ahmad R. A scientometric analysis and critical review of computer vision applications for construction. Automation in Construction 2019;107:102947. doi:10.1016/j.autcon.2019.102947.

[7] Van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 2010;84:523–38. doi:10.1007/s11192-009-0146-3.

[8] Perianes-Rodriguez A, Waltman L, Van Eck NJ. Constructing bibliometric networks: A comparison between full and fractional counting. Journal of Informetrics 2016;10:1178–95. doi:10.1016/j.joi.2016.10.006.

[9] Chen C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. Journal of the American Society for Information Science and Technology 2006;57:359–77. doi:10.1002/asi.20317.

[10] Freeman LC. A Set of Measures of Centrality Based on Betweenness. Sociometry 1977;40:35. doi:10.2307/3033543.

[11] Enke J, Glass R, Metternich J. Introducing a Maturity Model for Learning Factories. Procedia Manufacturing 2017;9:1–8. doi:10.1016/j.promfg.2017.04.010.

[12] Erol S, Jäger A, Hold P, Ott K, Sihn W. Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. Procedia CIRP 2016;54:13–8. doi:10.1016/j.procir.2016.03.162.

[13] Kreimeier D, Morlock F, Prinz C, Krückhans B, Bakir DC, Meier H. Holistic Learning Factories – A Concept to Train Lean Management, Resource Efficiency as Well as Management and Organization Improvement Skills. Procedia CIRP 2014;17:184–8. doi:10.1016/j.procir.2014.01.040.

[14] Ssemakula ME, Liao GY. Adapting the learning factory model for implementation in a laboratory. 33rd Annual Frontiers in Education, 2003. FIE 2003., vol. 2, IEEE; n.d., p. F2B_10-F2B_15. doi:10.1109/FIE.2003.1264697.

[15] Morell L, Trucco M, Bash C, Patel C. An engineering curriculum track for IT for sustainability. 2012 Frontiers in Education Conference Proceedings, IEEE; 2012, p. 1–6. doi:10.1109/FIE.2012.6462324.

[16] Lang S, Reggelin T, Jobran M, Hofmann W. Towards a Modular, Decentralized and Digital Industry 4.0 Learning Factory. 2018 Sixth International Conference on Enterprise Systems (ES), IEEE; 2018, p. 123–8. doi:10.1109/ES.2018.00026.

[17] Seitz K-F, Nyhuis P. Cyber-Physical Production Systems Combined with Logistic Models – A Learning Factory Concept for an Improved Production Planning and Control. Procedia CIRP 2015;32:92–7. doi:10.1016/j.procir.2015.02.220.

[18] Thiede S, Juraschek M, Herrmann C. Implementing Cyber-physical Production Systems in Learning Factories. Procedia CIRP 2016;54:7–12. doi:10.1016/j.procir.2016.04.098.

[19] Abele E, Metternich J, Tisch M, Chryssolouris G, Sihn W, ElMaraghy H, et al. Learning Factories for Research, Education, and Training. Procedia CIRP 2015;32:1–6. doi:10.1016/j.procir.2015.02.187.

[20] Kemény Z, Beregi RJ, Erdős G, Nacsa J. The MTA SZTAKI Smart Factory: Platform for Research and Project-oriented Skill Development in Higher Education. Procedia CIRP 2016;54:53–8. doi:10.1016/j.procir.2016.05.060.

[21] Mourtzis D, Vlachou E, Dimitrakopoulos G, Zogopoulos V. Cyber- Physical Systems and Education 4.0 –The Teaching Factory 4.0 Concept. Procedia Manufacturing 2018;23:129–34. doi:10.1016/j.promfg.2018.04.005.

[22] Mattsson S, Salunke O, Fast-Berglund Å, Li D, Skoogh A. Design concept towards a human-centered learning factory. Procedia Manufacturing 2018;25:526–34. doi:10.1016/j.promfg.2018.06.121.

[23] Blume S, Madanchi N, Böhme S, Posselt G, Thiede S, Herrmann C. Die Lernfabrik – Research-based Learning for Sustainable Production Engineering. Procedia CIRP 2015;32:126–31. doi:10.1016/j.procir.2015.02.113.

[24] Prinz C, Morlock F, Freith S, Kreggenfeld N, Kreimeier D, Kuhlenkötter B. Learning Factory Modules for Smart Factories in Industrie 4.0. Procedia CIRP 2016;54:113–8. doi:10.1016/j.procir.2016.05.105.

[25] Mavrikios D, Papakostas N, Mourtzis D, Chryssolouris G. On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework. Journal of Intelligent Manufacturing 2013;24:473–85. doi:10.1007/s10845-011-0590-9.

[26] Chryssolouris G, Mavrikios D, Mourtzis D. Manufacturing Systems: Skills & Competencies for the Future. Procedia CIRP 2013;7:17–24. doi:10.1016/j.procir.2013.05.004.

[27] ElMaraghy H, Moussa M, ElMaraghy W, Abbas M. Integrated Product / System Design and Planning for New Product Family in a Changeable Learning Factory. Procedia Manufacturing 2017;9:65–72. doi:10.1016/j.promfg.2017.04.008.