Process Innovation in Learning Factories: Towards a Reference Model

Maria Stoettrup Schioenning Larsen(✉), Astrid Heidemann Lassen, and Kjeld Nielsen

Department of Materials and Production, Aalborg University, Aalborg, Denmark
mssl@mp.aau.dk

Abstract. The fourth industrial revolution, also known as Industry 4.0, implies significant new technological opportunities for today's manufacturing industry. However, manufacturing companies still lack knowledge and skills on how to fully utilize these innovative technologies. This is in particular the case as regards development of process innovation. In order to advance this knowledge, the concept of learning factories is useful to support the manufacturer's learning and movement towards innovation. In short, a learning factory, that supports process innovation, can be described as a learning process for industry participants, which utilizes a learning factory to create rapid and innovative process solutions in industry based on the paradigm of Industry 4.0. Research on this topic is however still relatively scarce and scattered, meaning that no common conceptual frame of reference exists to support the research field of process innovation. Consequently, the theory building on innovation in the context of i4.0 is still fragmented and in its infancy, in spite of the rapidly increasing interest in this empirical phenomenon. To advance this domain of research, the current study unites and synthesizes existing research on process innovation in learning factories. Based on the findings of the literature review, the initial work of a reference model for process innovation in learning factories is presented.

Keywords: Learning factory · Process innovation · Industry 4.0 · Literature review · Reference model

1 Introduction

Industrial revolutions refer to paradigm shifts in industrial production, often caused by technology leaps. Thus far, three paradigm shifts have occurred and thereby also three industrial revolutions. Currently, the manufacturing industry is moving towards a fourth paradigm shift, which is generally recognized as the fourth industrial revolution or Industry 4.0 (i4.0) [1]. The overarching vision of i4.0 is to have intelligent end-to-end processes enabled by autonomous decision-making and cyber-physical systems throughout the supply chain [2, 3]. The implementation of i4.0 is expected to be enabled by a combination of Internet technologies, and "smart" machine and product technologies [1]. Despite agreement on the potential for using i4.0 technologies to make technological advancements in the production [4] and improve the competitiveness of the company [5], the implementation of innovative and valuable i4.0

Published by Springer Nature Switzerland AG 2019
F. Ameri et al. (Eds.): APMS 2019, IFIP AICT 566, pp. 658–665, 2019.
https://doi.org/10.1007/978-3-030-30000-5_80

solutions in industry is highly complicated, and requires a dedicated focus on developing new skills and competences [4, 6]. Creating process innovation by the use of i4.0 technologies is complex and abstract for companies [4] among other things due to lack of understanding of the potential caused by radical changes as a result of a shift in paradigm [7]. Furthermore, the speed of the technological development is increasing, which means that companies need to both learn about and implement new technologies faster than ever before to stay competitive. Therefore, existing learning methods related to i4.0 technologies may be too time consuming while they, at the same time, may restrict the participants' creativity and thereby the potential for achieving innovative solutions. In order to rapidly develop new knowledge on i4.0 technologies and construct innovative solutions on the basis of these technologies, companies may benefit from being more experimental in their learning approaches. At the same time, companies need to enter into new collaborations with e.g. supply chain partners to fully exploit the potential of i4.0. Consequently, new and faster learning methods which support the development of i4.0 manufacturing systems are required [1]. Several examples exist from both academia and industry where learning factories are used to train i4.0 solutions and thus development of i4.0 manufacturing systems [8, 9]. However, we argue that the concept of learning factories has a broader usefulness for conceptualizing the development of generic innovation methodologies for i4.0 manufacturing systems. Since research on this topic is scarce and fragmented, a common frame of reference is needed in order to create a common conceptual understanding of the research field. Reference models seek to create common understandings of e.g. a research field [10]. Therefore, the objective of this research is to present the initial work of a reference model, which can provide a common understanding of the use of learning factories to support process innovation in relation to i4.0. This is achieved by conducting a literature review, which seeks to answer the following research question: *How do learning factories support process innovation in i4.0?*

The paper is structured as follows: The applied research methodology is presented in Sect. 2. Afterwards, the findings of the literature review are presented in Sect. 3 and significant conclusions for establishing a reference model are emphasized. Lastly, findings and conclusion on the research are presented in Sect. 4.

2 Methodology

A structured literature review was made which addresses the research question: *How do learning factories support process innovation in i4.0?*

The initial applied search string was: "learning factory" OR "learning factories". Additionally, an initial search on innovation in learning factories was made. The chosen database was Web of Science, which ensures the academic standards of chosen publications. The search provided 192 hits. Upon first round of revision of the material, it became clear that most of the retrieved research focused on learning factories in education environments and that only limited research was related to industry participation. This led to initiation of a second round of literature search, which focused on capturing research on the topic, which could potentially have applied an adjacent terminology to learning factories. Combinations of several terms related to the research objective were tested. The terms were found in papers related to the research topic and through inputs from experienced researchers in the fields of robotics and automation, manufacturing systems, and operations development. It was chosen to broaden the scope of the literature topics to be included in this research. Leavitt's Diamond model from the 1960's was used as inspiration for structuring both the literature search and the subsequent analysis. The model was originally used for describing and analyzing organizations based on four parameters: Structure, technology, people, and task [11]. Through the four parameters, process innovation in learning factories was investigated in relation to the technologies in center of the innovation (technology), the people who learn by using the learning factory (people), the tasks these people do in relation to the innovative technology (task), and the applied learning process (structure) to answer the research question. Three search strings for each of the four parameters were constructed to search for literature. Only papers published after 2008, written in English language, and with a subject related to i4.0 innovation in learning factories in the manufacturing industry were included. This means that e.g. research on learning factories in education environments was excluded. Based on these criteria, the three most cited articles for each search string were selected for analysis, thus 36 articles have been selected in total.

3 Literature Review

This section presents the analysis of the papers retrieved through the literature search. Each analysis is rounded off with a summary of those findings which are of particular relevance to process innovation learning factories.

3.1 Structure

Technological process innovation is important for manufacturers' competitiveness in the market [5, 12]. Consequently, learning approaches which boost innovation in manufacturing are crucial [13]. Learning factories are applicable of providing the format and methodologies for this, since learning factories improve the learning productivity [7]. Several learning factories have been installed at universities and research institutions for research, education and/or industrial training [8, 14, 15]. However, the learning processes in learning factories and their objectives differ. Wagner et al. [8] for example studied learning factories focusing on changeable and reconfigurable manufacturing systems and concluded that only few learning factories have changeability characteristics and thus may be used to develop innovative solutions in regard to manufacturing system changeability and reconfigurability. Schallock et al. [15] found that more learning factories are being oriented towards i4.0 topics. The learning factory at Ruhr-Universität Bochum focuses on resource efficiency, management and organization, and process optimization to improve the workers' ability to accommodate changes in the production [14]. This corresponds to the findings of Abele et al. [13] who discovered that learning factories are often used to develop industry participants' ability to manage complex and unfamiliar situations. An example of a learning process related to i4.0 is described by Schallock et al. [15]. The training in the learning factory consists of two parts: One for the high-level managers and one for the line managers. The high-level managers are first coached and prepared for leading the change process of implementing i4.0. Afterwards, the line managers have two trainings. The first is a basic training, which introduces general principles needed for the second part. The second training focuses on i4.0 technologies and the implementation of these in production processes. After completing the training in the learning factory, the organization receives guidance and coaching on-site in the following six months. Another example is the learning process at the learning factory at Ruhr-Universität Bochum, which is centered around business games and simulations of real production processes [14]. Tisch and Metternich [16] present seven success factors for methodical modelling of learning processes and make suggestions for how each of the seven factors can be addressed through learning factories to build successful learning factories.

The literature furthermore indicates that different types of collaboration have a positive influence on learning. According to Macher and Mowery [17] manufacturers in the semiconductor industry that use diverse teams for problem-solving and co-locations, which strengthens the relations between employees in manufacturing and development, learn faster. Additionally, Un and Asakawa [5] found that a R&D collaboration between a manufacturing company and a university positively affects process innovation at the manufacturing site, which also supports the findings of Abele et al. [7] who found that complexity and costs of translating research results into operations can be costly for especially smaller companies.

The main goal of learning factories differs based on their application. For research purposes the main goals are often technological and/or organizational innovation, whereas for education and training of industry purposes, the main goal is to effectively develop competences [13]. Though, according to Abele et al. [7] learning factories would benefit from having a closer relation to innovation.

Based on this, it can be concluded that the use of learning factories differs depending on whether the purpose is related to industry or research. Currently, the use of learning factories to support innovation is related to the research domain, which however indicates that learning factories may be used to create process innovation in industry. Furthermore, there are indications that collaborations between industry and universities have a positive impact on process innovation.

3.2 Technology

New, innovative technologies are introduced with ever-increasing frequency, which gives manufacturing companies new possibilities for improving production processes. However, as mentioned before this also sets requirements for rapid knowledge acquisition and solution design for future manufacturing systems [18]. Learning factories support this process by focusing on new technologies and methods in their learning goals. Some learning factories use a holistic view by exploring topics such as i4.0 technologies and methods [19, 20], digital solutions [19], cyber physical production systems [20] and Internet of Things technologies [21, 22] whereas other learning factories focus on specific technologies and methods. Examples of these are industrial robots [18], logistics systems [23, 24], digital twins [25], and agility in operations [26]. The main focus in current use of learning factories is related to specific technologies and methods and only little attention is given to develop conceptual understandings of i4.0 in spite of it being a new manufacturing paradigm which may therefore require development of an overall understanding of i4.0 manufacturing systems.

3.3 People

Competence development is a recognized target of learning factories [27], which for instance should prepare industry participants for successful implementation of innovative i4.0 technologies [28]. The employees in focus are e.g. shop-floor workers [29], engineers from areas of expertise related to production [30], and employees from small and medium sized enterprises since they need information and innovative solutions which fit their corporate size and needs [31, 32]. According to Tisch et al. [33] most existing learning factories' industrial target is engineers. However, possible target groups may also be i4.0-specific roles, which have not yet been created [34]. Participants are primarily trained in homogeneous groups [33], though to reflect real workplace situations, Tisch et al. [33] propose to design learning processes which also focus on heterogeneous target groups. According to the findings of Macher and Mowery [17] presented in Sect. 3.1, using heterogeneous groups may also imply faster learning.

Participation in learning factory learning processes does not necessarily imply improved competences for the participants [27]. Therefore, in an attempt to avoid this problem, Enke et al. [35] suggest to compare the companies' actual state to the wished target state and based on this, design competence-oriented learning processes.

Based on this, it can be concluded that current research focuses on developing shop-floor employees' competences so that they are capable of implementing and operating i4.0 solutions and only limited attention is given to the development of management.

3.4 Task

Through learning factories, employees from industry should get hands-on experience with innovative i4.0 technologies. However, to achieve this, suitable learning methods and tasks must be applied [36, 37]. Therefore, Schuh et al. [37] studied factors relevant for creating a learning process, which increases the efficiency for participants to learn innovative i4.0 characteristics. Several learning processes put emphasis on training employees in the implementation of innovative technologies (see e.g. [38–41]) through practical, hands-on application, which is often combined with theoretical lectures. For instance, in the learning process described by Prinz et al. [42], the participants start with a theoretical introduction to i4.0 and assistance systems. This is followed by several hands-on simulations starting with a complex production with no assistance system and ending with a fully integrated assistance system to show the participants the differences. The learning process ends with a best-practice tour [42]. Several other learning factory concepts have also used simulation tasks (see e.g. [4, 43]) where the main objective is to transfer knowledge on innovative technologies from research institutions to industry. Consequently, it can be concluded that there is a tendency to use predefined simulation tasks for participants to learn about i4.0 and not using tasks which support innovation.

4 Findings and Conclusion

As this research shows, research on process innovation in learning factories is scarce. Consequently, to support future research in this area, a common frame of reference needs to be established. The findings of the literature review are used to construct a discussion on using learning factories to support the creation of process innovation, and thereby introduce the initial work of a reference model in this section.

The vision of an i4.0 factory consists of integrated seamless processes, which are able to efficiently control the increased complexity resulting from accommodating customers' unique requirements. Modularity, flexibility, complexity management, data exchange, and i4.0 technologies are examples of tools and methods, which support the development of the factory of the future. However, i4.0 is not limited to the implementation of isolated innovative methods and technologies, but is a new paradigm that requires manufacturers to see i4.0 from the perspective of the whole manufacturing system and its supply chain. Consequently, to avoid sub-optimizing individual production processes, the company's management needs to acquire a conceptual understanding of the i4.0 paradigm to use as guiding principle for individual i4.0 development projects. i4.0 learning factories could be used to develop this conceptual understanding. However, from this research it is evident that the current research focus in learning factories is to transfer knowledge on innovative i4.0 technologies to implement these in the production and not to develop a conceptual understanding of the i4.0 paradigm and support process innovation. Current focus is on employees who implement and operate the technologies and as a result of this a managerial perspective is lacking. Therefore, compared to existing learning factories, learning processes need to also support the generation of the conceptual understanding of i4.0 by using a management perspective. Additionally, the findings indicate that simulation is a frequently used method in learning factories which means that focus is on making knowledge transfer from research institutions to industry participants on i4.0 technologies and methods. However, if learning factories should support process innovation, this would require tasks and learning processes which encourage the participants to experiment and be creative.

A learning factory for process innovation distinguishes itself from existing learning factories because of its main focus being to create innovation in industry. Consequently, with an offset in the findings of this research we can describe the characteristics of a process innovation learning factory which stand out from existing use of learning factories. A process innovation learning factory can, therefore, be described as a learning factory which supports process innovation in industry through tasks that may be experimental and encourage creativity compared to existing learning factory approaches. Furthermore, to succeed, these learning factories should support the long-term and visionary development of i4.0 manufacturing systems, and thus focus on development of a conceptual understanding of i4.0 besides focus on individual i4.0 technologies and methods which are already used in learning factories today.

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