Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 00 (2019) 000–000

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

9th Conference on Learning Factories 2019

Audit - and then what? A roadmap for digitization of learning factories

André Ullrich[a,*], Judith Enke[b], Malte Teichmann[a], Antonio Kreß[b], Norbert Gronau[a]

[a]*University of Potsdam, August Bebel Str. 89, 14482 Potsdam, Germany*
[b]*Technical University Darmstadt, Otto-Berndt-Str. 2, 64287 Darmstadt, Germany*

Abstract

Current trends such as digital transformation, Internet of Things, or Industry 4.0 are challenging the majority of learning factories. Regardless of whether a conventional learning factory, a model factory, or a digital learning factory, traditional approaches such as the monotonous execution of specific instructions don`t suffice the learner's needs, market requirements as well as especially current technological developments. Contemporary teaching environments need a clear strategy, a road to follow for being able to successfully cope with the changes and develop towards digitized learning factories. This demand driven necessity of transformation leads to another obstacle: Assessing the status quo and developing and implementing adequate action plans. Within this paper, details of a maturity-based audit of the hybrid learning factory in the Research and Application Centre Industry 4.0 and a thereof derived roadmap for the digitization of a learning factory are presented.

Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.

Keywords: Audit; Digitization; Learning Factory; Roadmap

1. Introduction

The majority of learning factories face challenges from recent technological advancements such as digital transformation, the Internet of Things (IoT) or Industry 4.0. Traditional approaches are not sufficient to address the needs of learners against the background of current technological developments. [1,2]. Implementation approaches of new technologies begin to penetrate manufacturing and therefore, learning factories need to follow suit if they wish to proactively reduce the competency gap that initiated them. They widely evolve and transform into digitized learning

* Corresponding author. Tel.: +49-331-977-4561; fax: +49-331-977-3406.
E-mail address: aullrich@lswi.de

2351-9789 © 2019 The Authors. Published by Elsevier B.V.
Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.

factories for being prepared for this evolution [3]. Within this, they address new topics in the field of digitization in their curricula or use new, digital possibilities and techniques in their didactic concept. Nevertheless, existing learning factories struggle with implementing IoT-technologies systematically, since there is no clear picture which specific requirements are to cover, especially when they are used as testing grounds. Therefore, contemporary teaching environments need to be changeable for quick and easy adaptions towards individual action problems of potential learners and the learning content in both theoretical and practical sessions such as employed technologies. New didactic concepts and new technologies, such as smart wearables, AR/VR glasses, or drones have to be incorporated. For this reason, a strategic roadmap that guides and enables transformation [4] is required, for being sustainably effective and to satisfy customer needs. This necessity of transforming towards digitized learning factories through continuous improvement leads to another problem: Assessing the status quo and developing and implementing appropriate action plans. For this purpose, a target state must be defined, the current status needs to be captured and evaluated, respective action alternatives identified, prioritized, and implemented [5].

The goal of this paper is to present details of a maturity-based audit of the hybrid learning factory (Sec. 2) in the Research and Application Centre Industry 4.0 (RACI4.0) at the University of Potsdam and a thereof derived roadmap for the digitization of the learning factory. This is accomplished on the basis of audit results (Sec. 3) and a literature as well as market analysis of available technologies. The gathered insights were integrated into workshops in which the participants created and refined the roadmap (Sec. 4). Thus, the specific contribution lies in a transferrable recommendation for action for the development towards a digitized learning factory.

2. Use case hybrid learning factory in the Research and Application Centre Industry 4.0

Learning factories are learning environments in which participants are trained by the usage of simulated real production processes, which are as realistic and authentic as possible [6]. They offer a basis for self-controlled and informal learning [7] and pursue an action-oriented approach for the competency development by means of structured self-learning processes that are supported by different teaching methods [8]. These teaching methods move the teaching and learning processes close to real industrial situations [1]. Digitized learning factories cover topics of digitization, make use of new digital possibilities within their didactic approach, and "make use of digital tools for the purpose of learning production related concepts and subjects" [9]. That is for example: relevant aspects of production are hardware- and/or software-based replicated and can be tested, investigated, and simulated for the purpose of conveying skills and competencies.

Fig. 1. Hybrid teaching and learning environment in RACI4.0.

The learning factory in the RACI4.0 [10] comprises a hybrid simulation environment (Fig. 1), which combines the benefits of virtual and hardware simulation in order to design or analyze industrial manufacturing processes or to teach, learn and understand the advantages of using new technologies in industrial processes. The main physical components are work pieces and machine tool demonstrators as well as conveyors which connect various machine tool demonstrators. Additionally, IoT devices such as AR/VR glasses, tablets, smart watches, robots, smart products and machines are integral elements and in theoretical and practical focus within learning factory sessions. An ulterior strategic goal is to offer direct or simulated experience with practical relevant up-to-date technologies in production.

The didactic concept comprises a variety of learning modules for industrial competencies, focusing on the development of IoT-competencies. The underlying approach is subject-oriented and scenario-based learning for enabling competencies in the areas of process, organization, and interaction competencies [11]. Therein, trainers support learners within the processes necessary to acquire intended competencies. The scenarios [12] are either standardized from a predefined repository or an accurate simulation of the real processes where the employees (will) work (in the future). These scenarios can be merged into a whole teaching and learning environment and are designed micro-, meso-, and macro-didactical. Within the scenarios, variable process structures are worked out.

3. Maturity-based analysis of learning environments to identify improvement potentials

Learning factories like RACI4.0 are facing challenges comparable to those of real factories. To stay competitive and realize their full potential, organizations use maturity-based externally executed assessments. They can include the analysis of a current state, the comparison with a future state based on best practices and the dedication of an individual development path for the assessed organization [13]. In recent years a maturity model for learning factories was developed, which estimates the current situation of a learning factory in one of five maturity levels [5]. The model covers requirements in 24 different action fields. For the analysis of the current state of a learning factory, a questionnaire is executed as well as visits to the learning environment, observations of learning modules and examination of documents. From this information, each requirement is rated on a 0 to 3 scale of fulfillment. The result of the assessment is an appraisal for each requirement. Overall, 245 requirements are assessed. To derive the current maturity level, the minimum evaluation in each action field is decisive, which is equal to the minimum valuation of all requirements assigned to this action field. This uncovers most of the potential and increases the need for improvement. The audit results are summarized in an audit report, which is structured by maturity levels and action fields. In this report, one or more recommended actions are listed for each requirement with a result less than 3. The number of recommended actions varies depending on how much the evaluation of the requirements differs from 3.

The assessment of the RACI4.0 identified a total of 159 recommended actions. Out of these 13 should be realized to reach the next maturity level. Main action fields for the recommended actions are ´Develop and implement strategy` and ´Manage change`. These two action fields emphasize in particular the strategic further development of learning factories and examine important requirements therefor. Thus they are also of outstanding importance for the development towards digitized learning factories. 16 of the 159 recommended actions are related to this two action fields, which interact with other action fields: E.g., ´Define intended competencies` and ´Design didactic concept` should also be considered in alignment of the organizational and technological changes induced by such a transformation. Through digitalization, new competencies are required [15] and new didactic concepts reach market readiness. According to this, the technical configurations of the learning factory should be analyzed to implement the intended competencies and the didactic concept in the learning environment (action field ´Adapt learning environment`). On the basis of such an audit, the operating organization of the learning factory decides how the recommended actions will be implemented and what priorities will be set. Figure 2 shows the results of the audit (extract of requirements, rating current state), the target state derived from the aimed maturity level, recommended actions (extract from the audit report) and guiding questions for a specification of the recommended actions. In addition, the average rating of all learning factories examined is presented. In comparison to most of the other learning factories analyzed, especially in the two focused action fields potentials for improvement could be identified.

Audit

Action field	Requirement	Rating CS	Rating TS	Rating Ø	Recommended actions from audit	Guiding questions to specify actions further
Action field ´Develop and implement strategy`	Definition of action guiding strategy	1	3	2,1	Define an action guiding strategy.	Which aspects do the operating organization of the learning have to consider strategically?
					Align objectives with a long-term strategy.	Which high-level objectives are considered for a long-term strategy?
	Relationship between strategy and individual objectives	1	3	2,0	Formalize the relationship between strategy and individual objectives.	How is this relationship formalized?
					Document the relationship between strategy and individual objectives.	How is this relationship documented in a transparent way?
Action field ´Manage change`	Observation and consideration of new market trends	0	3	2,4	Observe new market trends.	What are the main new market trends for digital learning factories?
					Consider new market trends systematically.	What are the most important market trends in relation to the developed strategy?
					Evaluate the influence on competitiveness of new market trends.	Which market trends have the greatest influence on competitiveness?
	Consideration of new concepts	2	3	2,4	Consider new concepts regularly and systematically for an adaptation in the learning factory.	What are the most important concepts (technological, didactic) in relation to the developed strategy?

Roadmap

Legend: CS: Current state TS: Target state Ø: Average of all examined learning factories

Fig. 2. Results from audit and transformation of recommended actions.

4. Roadmap for digitization of learning factories using the RACI4.0 example

The conducted audit unveiled undeniable deficits, especially on the internal strategic level and the external level of screening new market trends systematically. To provide strategy and decision support, a roadmap for RACI4.0 was developed, which emphasizes the further transformation towards a digitized learning factory, since the focus lies on IoT-technologies [11]. Additionally, the digitization of industrial processes proceeds [2]. Therefore, it is aimed to constitute a continuously contemporary testing and learning field for technology implementation in factories. Roadmaps consist of elements, structural and temporal relations among the elements and are simplified visualizations of future developments, which are relevant to organizations. They provide an extended look at the future of a specific field that represents a vision of science and technology, as well as a way to identify, evaluate, and select strategic alternatives [4]. Especially technology roadmaps are a formalized method to assess future technological developments within a constantly changing environment [15]. Thus, they present a framework to help, plan, and coordinate (technological) developments at any level [16]. Additionally, they serve the purpose of strategic planning, executing, or identifying gaps and opportunities as well as helping to identify those areas that have high potential [4].

Following an expert-based approach, the consecutive steps were conducted for developing a prospective technology push and requirement pull roadmap: 1. evaluation of the current situation, 2 identification of potentials, 3. selection and evaluation of potentials, 4. creation of roadmap [17]. Step 1 and step 2 are directly addressed and covered by the maturity model-based audit. Additionally, basic research of drivers, technologies and market requirements was conducted by students following a scenario development approach proposed by [18]. Therein, e.g., driver such as big data, digitization, Internet of Services, cyber physical systems and Internet of Things were identified [2,19,20]. Furthermore, science and technology programs such as announcements of the EU *Horizon 2020* were monitored to identify further external potentials. Afterwards, iterative expert workshops were conducted to, firstly, select and evaluate potentials based on the recommended actions and guiding questions from the audit (step 3), and, secondly, to create and refine the levels, elements and relations of the roadmap (step 4).

The roadmap serves as a basis to strategically implement the audit recommendations. The action field ´Develop and implement strategy` unveiled four major recommendations: First, ´Define an action guiding strategy`, which is addressed by the respective items (and their relations) of the market requirements, topics and technologies in block *a* in Fig. 3. The second recommendation ´Align objectives with a long-term strategy` is taken into account by using a roadmap to operationalize the ulterior vision of offering experience with up-to-date production technologies, against the background of the major internal core competence of IoT technologies. The third recommendation, ´Formalize the relationship between strategy and individual objectives`, is addressed generally by developing the roadmap and specifically by connecting the structural with a temporal relation (block *b* in Fig. 3). The fourth recommendation ´Document the relationship between strategy and individual objectives` is addressed by both, this external communication and further internal documents. The action field ´Managing change` is inherently addressed in the roadmap: e.g. a consideration of megatrends is reflected by the driver, new market requirements, and technologies and their interdependencies. The major recommendations here are ´Consider new market trends systematically` and ´Evaluate the influence on competitiveness of new market trends` (block *c* in Fig. 3), were conducted as described above [cf. 18]. ´Observe new market trends` is conducted via continuous market analyses and participating in topic related conferences. On this basis, the recommendation ´Examine and consider new concepts for an adaption in the learning factory` (block *d* in Fig. 3) is also realized. Thereby, the consideration and application of new concepts such as didactic approaches (e.g. game-based, action-oriented) [2,8] or conveyable competence facets like interaction or environmental competence [11] were specified.

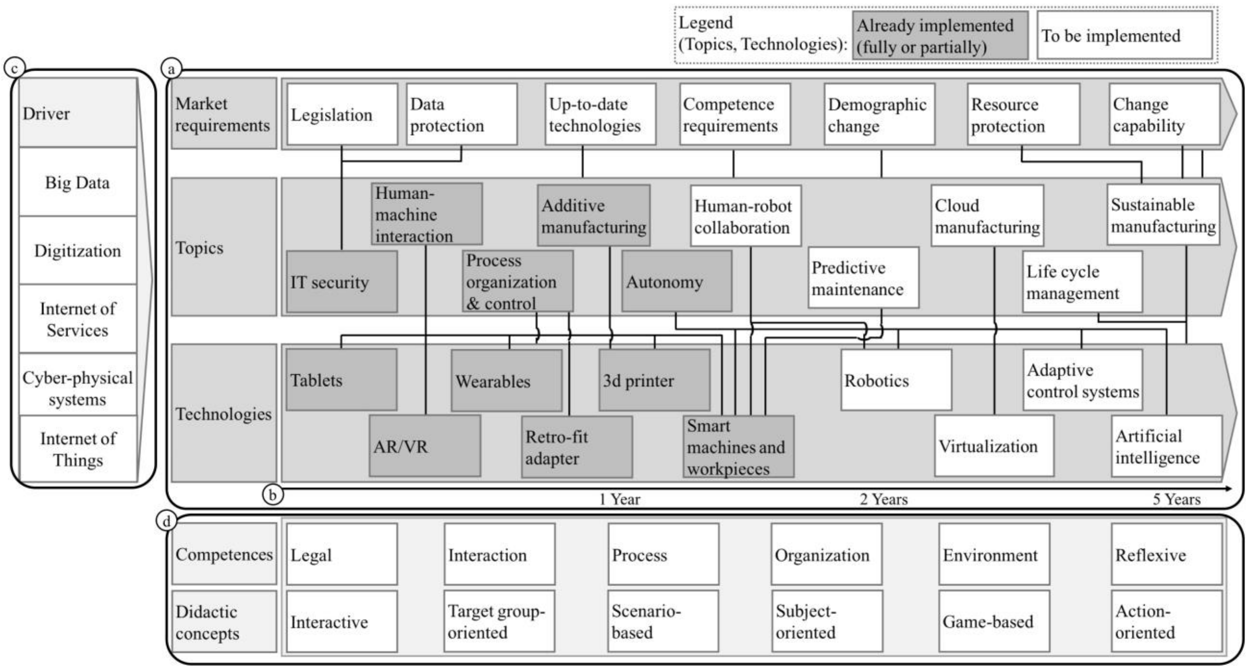

Fig. 3. Roadmap for digitization of RACI4.0 learning factory.

The inherent structural and temporal relations of the roadmap represent the prioritization of goals and developments regarding topics and technologies. Coming from the market requirements there are two meta-requirements: ´Demographic change` and ´Change capability` which address flexibility regarding topics supplied and technologies applied. The latter is also influenced by the demand for ´Up-to-date technologies` [2]. Furthermore, ´Legislation`, ´Data protection`, ´Resource protection`, and especially diversely induced ´Competence requirements` poses present and forthcoming challenges for learning factories. The major topics already partially or fully covered are ´IT security`, which is influenced by legislation requirements, and ´Process organization & control` within respective framework settings. ´Human-machine interaction` is related to technologies like tablets, AR/VR, and a smart watch that are already implemented just like a ´3d printer`, which is directly connected to the topic of ´Additive manufacturing`. Integral technologies for developing towards a digitized learning factory are ´Smart machines and work pieces` [19] that are able to operate autonomously (´Autonomy`), to learn and anticipate future events, such as maintenance based on throughput units, and interact with other machines or robots. Furthermore, this topic can be extended by technologies like ´Adaptive control systems`, or ´Artificial intelligence`. One necessary technology for digitization of real as well as learning factories are the so called ´Retro-fit adapter`, which enable the connection of old, natively non digital machines to the factory's online network. Topics such as ´Human-robot collaboration`, and ´Predictive maintenance` are mostly related to ´Smart machines and work pieces` and ´Robotics`, which represent the major ongoing and next technological features to be expanded and integrated. ´Virtualization` technologies and the topic of ´Cloud manufacturing` supplement each other. ´Life-cycle management` and ´Sustainable manufacturing` are further topics to be integrated, that are driven by ecological and digital demands and enabled by all of the new technologies.

The items of the competence areas and didactical concepts are not directly related to the topics covered and technologies applied in the learning factory. These represent a selection of possible complementary approaches. This roadmap outlines a framework of technologies and topics that are brought to the table by current market requirements and developments as well as competence areas and didactical concepts. It guides the further development of RACI4.0 towards a digitized learning factory. It also can serve as an orientation framework for digitizing learning factories in general. The respective time frame, element order or elements themselves are, however, not compulsorily applicable for every learning factory. Diverse orders or different elements are relevant, in dependence of individual goals, framework conditions, and recommended actions of the maturity model.

5. Conclusions

This paper presents an exemplary roadmap for digitization of learning factories based on an external audit for learning factories that was applied at RACI4.0. The maturity-based audit of learning factories is an useful tool to systematically determine the status quo and initiate future development of learning factories. Especially the recommended actions unveil potentials. In the present case, the vision of a digitized learning factory was developed by considering the action fields ´Manage change` and ´Develop and implement strategy` and manifested in a roadmap. An underlying goal of digitized learning factories is to sensitize participants and develop their competencies in digital technologies, that is, to foster technology acceptance and handling as well as to create action capable employees in digital work environments. This roadmap is specifically designed for RACI4.0. It, however, might contain transferable aspects that can generally guide the development towards digitized learning factories. Thereby, mainly new technologies, didactic concepts, and up-to-date topics are decisive success factors.

Acknowledgments

The authors would like to thank the Bundesministerium für Forschung und Bildung (Federal Ministry of Education and Research, BMBF) and the Bundesinstitut für Berufsbildung (Federal Institute for Vocational Education and Training, BiBB) for financial and administrative support during the project "Quality development of complex learning systems on the example of learning factories for production" (21IAWB104).

References

[1] E. Abele, J. Metternich, M. Tisch, G. Chryssolouris, W. Sihn, H. ElMaraghy, V. Hummel, F. Ranz, Learning Factories for Research, Education, and Training, Procedia CIRP, 32 (2015) 1–6.
[2] acatech, Kompetenzen für Industrie 4.0 – Qualifizierungsbedarfe und Lösungsansätze, Munich (2016).
[3] B. Brenner, V. Hummel, A Seamless Convergence of the Digital and Physical Factory Aiming in Personalized Product Emergence Process (PPEP) for Smart Products within ESB Logistics Learning Factory at Reutlingen University, Procedia CIRP, 54 (2016) 227–32.
[4] R. N. Kostoff, R. R. Schaller, Science and technology roadmaps, IEEE Trans. Eng. Manage., 48(2) (2001) 132–43.
[5] J. Enke, J. Metternich, D. Bentz, P.-J. Klaes, Systematic learning factory improvement based on maturity level assessment, Procedia Manufacturing, 23 (2018) 51–6.

[6] E. Abele, N. Eichhorn, Process Learning Factory – Training students and management for excellent production processes, in: Kuljanic, E. (Ed.) Advanced Manufacturing Systems and Technology, CISM, Udine (2008) 63-73.

[7] J. Enke, K. Kraft, J. Metternich, Competency-oriented Design of Learning Modules, Procedia CIRP, 32 (2015)7–12.

[8] M. Tisch, C. Hertle, J. Cachay, E. Abele, J. Metternich, R. Tenberg, A Systematic Approach on Developing Action-oriented, Competency-based Learning Factories, Procedia CIRP, 7 (2013) 580–5.

[9] A. Haghighi, N. S. Zadeh, G. Sivard, T. Lundholm, Y. Eriksson, Digital learning factories: Conceptualization, Review and Discussion.,The 6th Swedish Production Symposium (2014).

[10] RACI4.0, Research and Application Center Industrie 4.0, www.azi.lswi.de (accessed on 11.11.2018).

[11] N. Gronau, A. Ullrich, M. Teichmann, Development of the Industrial IoT Competences in the Areas of Organization, Process, and Interaction Based on the Learning Factory Concept, Procedia Manufacturing, 9 (2017) 254–61.

[12] M. Teichmann, A. Ullrich, B. Bender, N. Gronau, Mobile IIoT-Technologien in hybriden Lernfabriken - Szenariobasierte Entwicklung von Handlungskompetenz im Anwendungszentrum Industrie 4.0, Industrie 4.0 Management, 34(3) (2018) 21–4.

[13] M. Röglinger, J. Pöppelbuß, What makes a useful maturity model? A framework for general design principles for maturity models and its demonstration in business process management, ECIS 2011 Proceedings (2011).

[14] J. Enke, R. Glass, A. Kreß, J. Hambach, M. Tisch, J. Metternich, Industrie 4.0 – Competencies for a modern production system, Procedia Manufacturing, 23 (2018), 267–72.

[15] D. Probert, N. Shehabuddeen, Technology road mapping: the issues of managing technology change, IJTM, 17(6) (1999), 646–61.

[16] M. L. Garcia, O. H. Bray, Fundamentals of technology roadmapping, 97th ed. Sandia Nat. Labs., Albuquerque (1998).

[17] M. Seiter, C. Bayrle, S. Berlin, U. David, M. Rusch, O. Treusch, Roadmap Industrie 4.0: Ihr Weg zur erfolgreichen Umsetzung von Industrie 4.0, tredition GmbH, Hamburg (2016).

[18] E. Tsui, N. Dragicevic, Using the scenario development and personal learning environment and network to support curriculum design, Management & Marketing, Challenges for the Knowledge Society, 13(2) (2018) 848–58.

[19] J. Lee, B. Bagheri, H.-A. Kao, A cyber-physical systems architecture for industry 4.0-based manufacturing systems, Manufacturing Letters , 3 (2015) 18–23.

[20] M. Hermann, T. Pentek, B. Otto, Design Principles for Industrie 4.0 Scenarios, in: 49th HICSS, IEEE (2016) 3928–3937.