Creative Education, 2024, 15, 1337-1358
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Investigating Learning Factories as a Learning Environment in Vocational Education and Training

Sebastian Anselmann[1], Uwe Faßhauer[1], Lars Windelband[2]

[1]Department of Vocational Education, University of Education Schwäbisch Gmünd, Schwäbisch Gmünd, Germany
[2]Department of Vocational Education, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
Email: sebastian.anselmann@ph-gmuend.de, uwe.fasshauer@ph-gmuend.de, lars.windelband@kit.edu

How to cite this paper: Anselmann, S., Faßhauer, U., & Windelband, L. (2024). Investigating Learning Factories as a Learning Environment in Vocational Education and Training. *Creative Education, 15,* 1337-1358.
https://doi.org/10.4236/ce.2024.157081

Received: May 9, 2024
Accepted: July 12, 2024
Published: July 15, 2024

Abstract

Learning factories operate as intricate simulations of actual work and production procedures. Specifically, their purpose is to facilitate the cultivation of vocational skills aligned with the demands of Industry 4.0. This paper begins by exploring learning factories as progressive learning spaces, underscoring the significance of cyber-physical systems. Following this, it outlines the current state of implementation and conceptual advancement of vocational learning factories in German vocational schools based on preliminary survey findings. To gain insight, a descriptive quantitative survey with 41 items was developed. The items were operationalized from the main theoretical concepts and research articles on learning factories, with a focus on the operational process, the alignment of didactical components and items on the ongoing processes and maintenance of learning factories. In total, 69 vocational schools with operating learning factories took part in the survey. The questionnaire revealed a heterogeneous picture with regard to size, the departments involved and personnel development and training. Involved teachers often integrated only individual components and did so irregularly to integrate the topics covered in their lessons. The entire learning factory was rarely used, although the relevance and didactic value were known to the involved staff. Dealing with a learning factory requires extensive special knowledge of the technologies used. It encompasses all levels of the automation pyramid, as well as an embedded pedagogical curriculum. In addition, there is high time expenditure in terms of planning, coordination, setup and operation, which also includes constant training and maintenance.

Keywords

Learning Factories, Vocational Education and Training, Complex Learning

Environment

1. Introduction

Learning factories represent a complex simulation of actual work and production processes. Target groups for this real, dynamic production environment can include students, apprentices, professionals or individuals already in the workforce. Abele et al. (2019) and Faßhauer et al. (2021) identified four essential characteristics that must be fulfilled by a learning factory. These include the depiction of authentic work processes considering technical and organizational aspects, a dynamic work environment corresponding to a real value chain, the actual ability to produce a product in the learning factory and a comprehensive didactic concept for the integration of respective teaching and learning arrangements. Learning factories thus prepare learners for the participation and shaping of complex and dynamic work processes in a connected and digitized working world.

The focus is not only on developing primary competencies in handling specific tasks and working with objects but also on the training and acquisition of, among other things, teamwork competence in collaboration within the learning factory (also between different professions). Process competence is also addressed to understand and potentially shape the connections in the production process through the entire value creation process (Weyand et al., 2023; Petrusch et al., 2023).

As comprehensive as the challenge is for all involved actors, the actual gap in the research on this topic is surprising. While a number of studies address the concept of learning factories and their integration into respective education (see, for example, Faßhauer et al., 2021; Scheid, 2018; Soori et al., 2023), there is still a lack of a fundamental, research-based approach to learning factories as complex learning environments and a new learning space for vocational education, considering as many characteristic factors as possible. This especially includes a deep perspective on digital work processes as learning spaces in the 21st century. At the same time, research results on criteria for the successful application of learning factories in their respective contexts (training, further education and university education) are also missing.

As part of a joint project in the Quality Offensive for Teacher Education, jointly financed by the state of Baden-Württemberg and the Federal Ministry of Education and Research (BMBF), the project "Integrated Technical and Economic Didactics (TWIND)" examines conceptual developments in the context of learning factories. Therefore, this contribution reflects on the concept of vocational learning factories and the associated learning spaces. In addition, the initial findings from a descriptive exploratory survey focusing on the operational process of the learning factory and the use/orientation of didactic components are presented.

2. Theoretical Foundations

The German "dual" training system has garnered a solid international reputation (Clarke et al., 2020; Oeben & Klumpp, 2021). According to numerous experts, Germany's success in exporting high-priced goods is attributed to its technically skilled workforce (Pilz & Wiemann, 2020). A prominent characteristic of the dual training system is its twofold learning environment, encompassing vocational school and the company. This ensures the fusion of theoretical knowledge with hands-on experience, predominantly occurring at the company for three to four days per week. The training commences with a contractual agreement between the trainee and the company. Over the customary three-year training period, attending vocational school is obligatory (Cedefop, 2021). Additionally, trainees receive a progressively increasing salary as they progress in their vocational training. More and more learning factories are established for training and teaching to maintain the high standards in the dual training system, as well as in developing the demanded skills. Zinn (2014: p. 23) described the learning factory as a concept in which learners have authentic opportunities to work on professional tasks with profession-specific tools in a realistic learning environment. Therefore the learning factory should make a business context imaginable, in which real working conditions are simulated for learners. It is not a simple theory-practice supplement, but a complex, demanding spatial and didactic-methodical conceptualization.

To meet this high standard, learning factories are modularly structured. This allows for flexible responses to changing training situations as well as to the altered requirements of training companies. Moreover, continuous development and didactic fine-tuning are possible.

The more didactically demanding and technically complex learning factories (smart factories) at vocational schools are increasingly playing a key role in translating the technical complexity and innovative character of Industry 4.0 into a vocational work situation under realistic conditions.

Learning sites in vocational education undergo a continuous process of change and adaptation (Harteis, 2022). An expression of an innovative and flexible character is the integration of new learning sites, such as learning factories. Within the concept of learning factories, cyber-physical systems (CPS) can play a crucial role in innovating training to modern learning sites. The National Science Foundation (NSF, 2016) defined CPS as 'engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components' (NSF, 2016: p. 13). The realm of technology has undergone substantial transformation in recent decades. Components that once existed solely in mechanical or electrical form, particularly those describing logic, control and decision-making, are increasingly taking on the characteristics of embedded systems and software, known as cyber elements. The acronym "CPS" is commonly employed to depict technical systems constructed through the seamless integration of computational algorithms and the physical components on which they rely (NSF, 2016). In this context, "cyber" encompasses computers, software, data structures and networks that underpin decision-making within the system, while "physical" encompasses not only the components of physical systems (e.g., the mechanical and electrical elements of an automated vehicle) but also the physical environment in which the system operates, such as a production line or a modular learning factory. CPS is closely intertwined with terms such as the internet of things (IoT) and smart cities, as well as with the fields of robotics and systems engineering (Thiede et al., 2016). Liu and colleagues (2019) listed intelligent industrial manufacturing, intelligent transportation and smart power grids as examples of CPS. The characteristic feature is the transformation of traditionally isolated, automated systems into modern, interconnected intelligent systems. The goal is to connect occupational actors, systems and physical assets to generate significant economic value as a synchronized network. CPS features complexity, dynamic variability and heterogeneity arising from interactions between cyber and physical subsystems (Lee & Sehia, 2016).

Thiede et al. (2016) highlighted the opportunities provided by training in CPS. Such training serves as an alternative or complement to theoretical content in educational contexts and, with embedded learning factories, represents a promising didactic approach. As CPS gains importance in manufacturing, education and training are becoming key factors for successful implementation in companies. Using a simplified assessment system based on the components of a CPS, a tool was created for targeted use in learning environments on this topic. The approach aligns with corresponding processes and systems on an industrial scale, as well as with the required skills for development and operation (Gräßler et al., 2016). The goal was to implement CPS elements as flexible components in the learning factory. The main focuses in this highly networked learning factory system (learning factories for research and qualification purposes) included the following elements (Gräßler et al., 2016):

- Flexible reconfiguration of production control systems, decentralization of decision-making and execution
- Modularization of the production system
- Adaptive connection of all production participants
- Plug and produce
- Decentralized production planning system

The concept included the communication structure, decentralized production control and the heuristics and algorithms of each device in the factory to enable an autonomous, decentralized production control system. Each device in the production system had the ability to collect the information necessary for its own operation and communicate its status to other devices.

The actual design of learning factories with CPS is a complex process requiring detailed approaches to various aspects. Studies on the design and construction of learning factories have highlighted the limitations of the static concept of learning factories (e.g. Abele et al., 2019; Kreß et al., 2021; McHauser et al., 2020). Gräßler et al. (2016) emphasized that no design approach focuses on the goal evaluation, scalability and temporal feasibility of the learning factory concept as a whole. To make optimal use of the potential of CPS in learning factories and to unfold the potential of learning factories as places for future dynamic workplaces, it is necessary to think about and plan learning factories in a modular and interconnected fashion.

The demand for learning factories and their associated didactic means is immense, reflecting the increasing complexity of work processes. The high technical complexity in production processes in the context of Industry 4.0 is accompanied by high demands on the technical understanding of learners and educators. To understand and comprehend the work and business processes in the context of Industry 4.0, skilled workers in the industrial-technical fields, and increasingly also in the commercial fields, are confronted with this process understanding (Faßhauer et al., 2021).

In terms of design, construction, and potential development, Frielinck (2023), Gräßler et al. (2016) and Kreß et al. (2021) identified a range of design approaches for classifying learning factories in the context of research and qualification. In this context, deficiencies in the majority of existing learning factories were identified, covering the process through implementation and the operation of the completed learning factory.

- Learning factories largely lack a comprehensive didactic concept appropriate to the complexity of the subject.
- The design of learning factories is usually conceived of as a one-time project, with no detailed procedural model or set of necessary and optional modules. There is often no detailed procedural model for the design of learning factories.
- The success of a learning factory depends significantly on the development of competency-oriented learning modules. Well-structured, competency-oriented learning modules are required to achieve curricular anchored learning objectives.
- The design of the learning environment should consider the transfer from the learning factory to a real factory environment and should be highly realistic.
- A comprehensive evaluation program of learning factories and all involved stakeholder groups is crucial for further development.
- Learning factories are resource intensive and depend on continuous flexible adaptation and development of modules and requirements.
- Learning factories should reflect real factories and their challenges in as many facets as possible.
- Learning factories are usually immobile, especially first-generation learning factories. By incorporating CPS, virtual or simulated modules and Virtual Reality (VR) concepts, learning factories are expected to become more flexible and adaptable.

Sudhoff (2021) and Löhr-Zeidler et al. (2016) identified over 20 fundamental focal points for learning factories in vocational schools that can be represented in a (complete) facility. The range extends from digitization processes to production management processes, automation, artificial intelligence, product development, production planning and plant control through a manufacturing execution system (MES). However, the topics are not always linked to professional actions; questions about understanding and categorizing technology often dominate.

In addition, there are questions about the basics of product development, work planning, production control, production management and software engineering for production systems, which can be implemented within the learning factory when creating a product. The connection between product development and subsequent production is understandable (Gräßler et al., 2016).

Thus, learning factories combine a series of learning-promoting factors (Frielinck, 2023) that significantly influence knowledge transfer (Tynjälä et al., 2021). A didactically valuable learning environment based on the processes of connectivity between education and work (Zitter et al., 2021) includes, according to Rau (2004), the following skills:

- Incorporating one's own ideas in task execution
- Work intensity: time pressure, work pace, difficulty, workload
- Predictability: action and decision-making spaces
- Experience of control over a situation
- Immediate feedback on results
- Physical variation
- Bearing sole responsibility for an entire workgroup's work result
- Effectively using pre-existing knowledge in work activities
- Opportunities for further education
- Learning something new
- Task variety/diversity

The requirements for the development of competence in work have been determined to be predictability, task variety and feedback on results (Rau, 2004). The demands placed on vocational learning factories, as well as the associated challenges for knowledge transfer, reveal the complexity of this relatively new learning space. The survey described below aimed to lay the foundation for a research-based approach to vocational learning factories as complex learning environments and new learning spaces for vocational education, taking into account as many characteristic factors as possible. This makes learning factories a valuable environment, providing a deepened perspective on digital work and business processes as learning spaces in the 21st century (Mueller et al., 2023).

3. Research Design

Learning factories are considered promising and methodically complex learning spaces (Öztürk et al., 2022). However, there are currently few studies that investigate the use, orientation and success conditions of learning factories in vocational education.

3.1. Instrument Development

Due to the lack of existing research, a theory-guided exploratory procedure was applied to instrument development (Cohen et al., 2018; Flick, 2022). To cover the broadest spectrum possible, all items were developed based on previous research on individual aspects (e.g., Roll & Ifenthaler, 2020; Scheid, 2018; Windelband, 2023) or reflections (e.g. Faßhauer et al., 2021; Windelband, 2023). While there are only a few research studies on how a learning factory is conceptually and didactically designed, the importance of a learning factory for modern and especially digital work processes is well known.

Therefore, the questionnaire, with four categories and a total of 41 items, addressed this comprehensive approach:

A) Questions about the learning factory (14 items): These items inquired about fundamental characteristics of the utilized learning factory, including the involved departments, user groups and general purposes.

B) Questions about the process design of the learning factory (9 items): These items focused on specific features of the process design of the investigated learning factory. They covered thematic priorities, the simulation of product cycles, frequently used teaching and learning methods and additional topics from the school context.

C) Questions about the didactic components (8 items): This section mapped the competence structure models of vocational learning with eight comprehensive items. It also focused on attitudes towards the sustainable use of digital media in teaching and their added value from the perspective of responsible individuals.

D) Demographic data of the respondents (10 items): This section collected demographic data of respondents, with a particular emphasis on qualification and professional experience.

This questionnaire covered various background variables related to the use and conditions of vocational learning factories (e.g. size, type, usage behavior, capacity, acceptance, equipment, further development and collaborations). It addressed the leading actors, such as headmaster, operating manager and department leader, who were responsible for the learning factory. The target audience for these questions was the person responsible for learning factories at the respective vocational school. Table 1 shows the categories, selected examples of items and corresponding choices from the questionnaire.

Table 1. Categories, item examples and choices of the learning factory questionnaire.

Category	Item Example	Selection Options
A	How many years of professional experience do you have in total?	Open answer format
	What is the main purpose of the learning factory in operation? (based on Abele et al., 2015)	Single choice option • Support for training processes • Support for continuing education programs • Research on selected topics

Continued

	How often are individual components of the learning factory renewed or replaced?	Open answer field
B	Where do you see the thematic focus in the learning factory? (based on Sudhoff, 2021; Löhr-Zeidler et al., 2016)	Multiple choice answers possible • Improvement of production processes • Production management • Problem diagnosis and solution • Robotics • Human-machine interface • MES • Service and maintenance • Networking and data security (21 possible answers in total)
	Which areas of the product life cycles are mapped in the learning factory? (based on Becker et al. 2017)	Multiple answers possible. • Plant planning • Simulation • System design • Networking • System setup and commissioning • System monitoring • Process management • Visualisation/monitoring/coordination/organisation (10 possible answers in total)
C	What do you think is mainly developed in the learning factory? (Competence structure model of vocational learning; Lindemann, 2015; Sloane, 2005; Dilger & Sloane, 2005)	Five-point Likert scale, from 1 = not taught at all, to 5 = very well taught • Social competence • Professional and technical competence • Process competence • Personal competence • Language skills • Mathematical understanding • Symbols/interpretation of symbols and text • Methodological competence • Learning competence • Beliefs and values
	Which of these points do you agree with? (Zinn, 2014)	Five-point Likert scale, from 1 = strongly disagree to 5 = strongly agree • Problem-oriented teaching and learning processes are based on concrete professional situations. • It must be possible to develop problem-solving skills in work situations based on experience. • Work organisation and the use of planning strategies become learning principles. • Self-organisation and self-responsible group learning form the core idea of an action-oriented learning environment.

Continued

D	How many years of professional experience do you have in total?	Open answer format
	If you work in a school context, which qualification path did you choose?	Single choice option • Basic teacher training course • Studies in another subject area • Alternative access plus open answer field

Thus, in the main part of the questionnaire, the didactic-methodical components of instructional development and the process design of the learning factory were surveyed. Aspects of school personnel development, especially the recruitment and training of teachers for the use of learning factories, were likely to play a significant role. This was achieved in the questionnaire through items, for example, on the qualifications of the involved teachers (in accordance with Gössling et al., 2020). The compilation of the 41 items and the descriptive approach aimed to provide initial insight into learning factories as learning spaces in vocational education.

3.2. Implementation

In the context of an online-supported quantitative survey, comprehensive access to all vocational schools with Industry 4.0 learning factories in the southern states of Germany in Baden-Württemberg and Bavaria was established. Different vocational schools also cooperated in the implementation of a vocational learning factory. The focus on the southern German region was due to the widespread presence of learning factories there. Along with a letter of introduction and recommendation, a link to the questionnaire was sent through the Ministry of Economic Affairs Baden-Württemberg and the Ministry of Culture Bavaria. Informed consent preceded the questionnaire. Data collection was conducted according to the General Data Protection Regulation (GDPR) standards for online questionnaires. The average processing time for the questionnaire was 20 minutes.

3.3. Sample

The leading actors of each vocational school learning factory were asked to participate in the survey. Depending on the federal state, the institutions were titled, for example, "Learning Factories 4.0" (Baden-Württemberg) or "Learning Factory" (Bavaria). In recent years, Baden-Württemberg has advanced the concept through two initiatives regarding "Learning Factories 4.0", and Bavaria, through two funding initiatives, "Industry 4.0" and "Excellence Schools at Vocational Schools" (Wilbers & Windelband, 2021). Alone in Baden-Württemberg, 75 vocational schools were involved, accounting for approximately 65% of public vocational schools offering training courses in the metal and electrical professions. In this context, learning factories were understood as "networked systems", which made the abstract concept of Industry 4.0 tangible for junior and skilled workers. Numerous biographical and career development background questions were asked of the participating experts. A total of 69 questionnaires with corresponding experts from each school were analyzed. The average respondent age was 51 years (M = 50.90; Min = 34; Max = 62), and the job titles in the school service varied from study advisor to chief study director, with the majority holding the position of study director (28 mentions) or chief study advisor (19 mentions). In this position, they had been working, on average, for 8.5 years (M = 8.48; Min = 0.5; Max = 22). Overall, they had 23.5 years of professional experience (M = 23.51; Min = 3; Max = 41). Of the 52 individuals, all 52 stated that they had completed a basic teaching degree program to enter the position. Thirteen people mentioned an alternative entry, such as an engineering degree followed by pedagogical requalification. The focus of their work was, as expected, in the dual system (36 mentions) and in further education (19 mentions), as well as in the transition system (3 mentions). For professional development and in the context of lifelong learning, 54 individuals had participated in formal training over the last three years. Thus, 51 technical training sessions, 33 didactic training sessions, 31 technical training sessions and one for general school organization were reported (multiple responses were possible).

4. Results

The descriptive approach aimed to provide initial insight into learning factories as learning spaces. The descriptive analysis provided answers to questions such as which didactic components were extensively used, how the operation of the learning factory and complex teaching-learning arrangements interacted, what the actual spatial and technical equipment of the learning factory was, what possibilities the learning factory had to meet the requirements of Industry 4.0 and what level of utilization and acceptance a learning factory experienced within the vocational school. Additionally, aspects of school personnel development, especially the recruitment and training of teachers for the use of learning factories, played a role.

4.1. General Questions about the Learning Factory

This section presents fundamental characteristics of the employed learning factory, along with the involved departments, groups of people and basic purposes. It includes 14 items and sub-questions.

The surveyed vocational schools with Industry 4.0 learning factories presented a heterogeneous picture regarding a) their size, b) the involved departments and c) their personnel development and training.

a) In the majority, two (34 mentions) or three departments (21 mentions) are involved in each respective learning factory. Stronger involvement of even more departments was mentioned only four times. In eight cases, only one department was involved in the learning factory. These departments mainly covered training in the metal and electrical professions, both part-time and full-time, for technicians and possibly master classes, e.g., for industrial masters. Departments for vocational colleges and technical high schools also played a role. Thus, predominantly mechatronics engineers, IT specialists, industrial mechanics and product designers were trained. The spectrum also included machine and plant operators, industrial electricians, device and system electricians, toolmakers, machinists, precision mechanics and IT system electronics engineers.

b) On average, 81 teachers (M = 80.89; Min = 15; Max = 180) were employed at the respective schools. Significantly fewer teachers were involved in the learning factory itself. On average, six individuals (M = 5.89; Min = 1; Max = 14) were involved. In one-third of the schools, an additional supporting person was involved, e.g. for the operation and maintenance of the learning factory. In individual cases, external groups for software or trainers from dual-partner companies were also supportive. In this context, teachers often integrated only individual components in an irregular manner to cover the topics in their teaching. The entire learning factory was rarely used. More than 70 percent of the respondents stated that they only partially use the learning factory.

c) In accordance with Gössling et al. (2020), questions about the qualifications of the involved teachers were also asked. Eighty percent stated that there was no fixed or binding qualification program. Only 50 percent stated that attending training was required before participating in the learning factory. This usually included basic courses on operating the learning factory and software training on common programs. Most training was done as in-house teacher training and/or as introductory courses by the manufacturers of the learning factory. When asked about desirable training, more than 50 percent of the surveyed actors stated that no additional training was necessary. Recruitment for work at the learning factory ultimately occurred through motivated teachers in relevant subject areas. They were actively approached by department and school leaders or expressed a general interest. Specific recruitment programs or formalized training paths were not mentioned.

The average number of students for the entire institution was approximately 1400 (M = 1423; Min = 120; Max = 4800). However, only a small proportion of the students were regularly taught at the learning factory. The percentage of usage was significantly higher for technicians. **Figure 1** illustrates this, based on the determined values.

The following statements refer to the results concerning the learning factory itself. Due to the evolving structure of the learning factories, individual components are seldom renewed or replaced. Respondents indicated intervals of 3 - 5 years as routines for replacement. In general, the facilities were described as being too new to necessitate the replacement of entire structures due to defects. Therefore, often, only components affected by mechanical wear, defective small parts such as sensors, switching elements, connections or batteries were

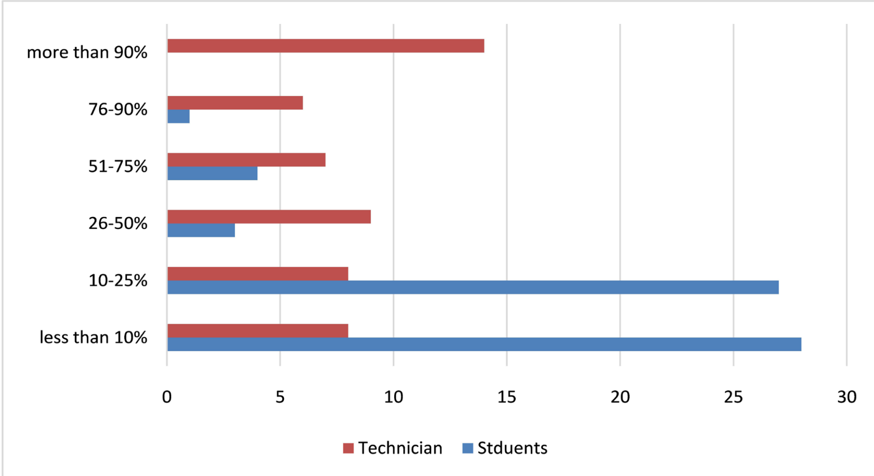

Figure 1. Percentage of individuals regularly taught in the learning factory.

exchanged. The learning factory itself was mostly seen as a dynamic project. Adaptations and improvements were firmly planned. This was reflected in part in the assessments of the learning factory's equipment, which are presented in Table 2.

Table 2. Assessments of the learning factory structure.

Item	M	SD
How would you describe the spatial equipment of the learning factory?	4.18	1.09
How would you describe the technical equipment of the learning factory?	4.31	0.94
How would you describe the capabilities of the learning factory to meet the requirements of Industry 4.0?	3.78	1.16
How would you describe the level of digitisation of your institution (e.g. vocational school)?	3.73	0.99
How would you describe the level of digitisation of the learning factory?	4.01	0.96
How would you describe the overall utilisation of the learning factory?	2.81	1.19
How would you describe the staffing of the learning factory?	2.82	1.23

1 = completely insufficient, to 5 = completely sufficient; M = mean; SD = standard deviation.

4.2. Questions about the Operational Process of the Learning Factory

Specific features of the process design of the examined learning factory were highlighted across 12 items. These included thematic focuses, simulation of professional fields, frequently used teaching and learning methods and additionally conveyed subject areas from the school context. The starting point was a question about the thematic focuses of a learning factory. Figure 2 shows these based on the frequency of mention. Multiple answers were possible in the responses.

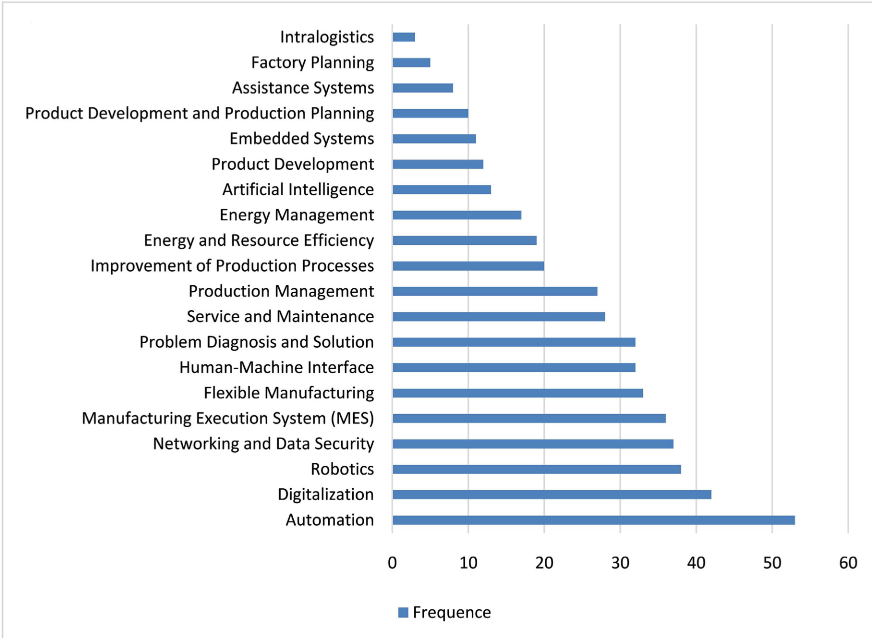

Figure 2. Thematic focus in the learning factory, according to Sudhoff (2021) and Löhr-Zeidler et al. (2016).

The main fields thus represented the current challenges and requirements for future-oriented education, with a focus on digitized and interconnected production. In addition, the representation of complex work steps and flexible alignment was relevant. Therefore, topics related to product development, production planning and overall factory planning were considered less crucial.

Given the possibilities of an increasingly digitized working world, a learning factory does not need to completely replicate all generic action fields for Industry 4.0 in a real environment. Simulation is an option. The nine generic action fields for Industry 4.0 identified by Becker et al. (2017) described the process from plant planning to troubleshooting in an operational plant. Table 3 shows the distributions, with multiple answers possible.

Table 3. Assessments of the learning factory structure.

Generic action fields	Real	Simulated	Not available
Plant Planning—Simulation	9	17	35
Plant Construction—Networking	37	6	16
Plant Setup and Commissioning	42	5	11
Plant Monitoring	44	1	14

Continued

Process Management—Visualisation/Monitoring/Coordination/Organisation	38	11	10
Data Management—Handling of Operating Data/Software Access/Parameterisation/Programming	39	12	9
Maintenance	35	5	19
Repair—Also Software-Supported on Networked Systems	22	5	32
Troubleshooting and Resolution	43	7	9
Additional areas (free-text field)	1 (not mentioned)		

A differentiated picture also emerged in the composition of the learning factories. Forty-four facilities relied entirely on purchasing ready-made modules externally for the learning factory, while 19 facilities complemented the delivered modules with in-house production. Ready-made industrial components were the standard for the majority of facilities (43 mentions), while eight facilities also used nonindustrial components in the context of the learning factory. Overall, cyber–physical components played a greater role, with 32 mentions, than virtual technical components with 22 mentions.

In addition to common subject-specific teaching components, other thematic areas were conveyed in the learning factory. **Figure 3** shows a ranking of additional thematic areas based on frequency, which, according to Sudhoff (2021), was directly related to operation and training in the modern production world.

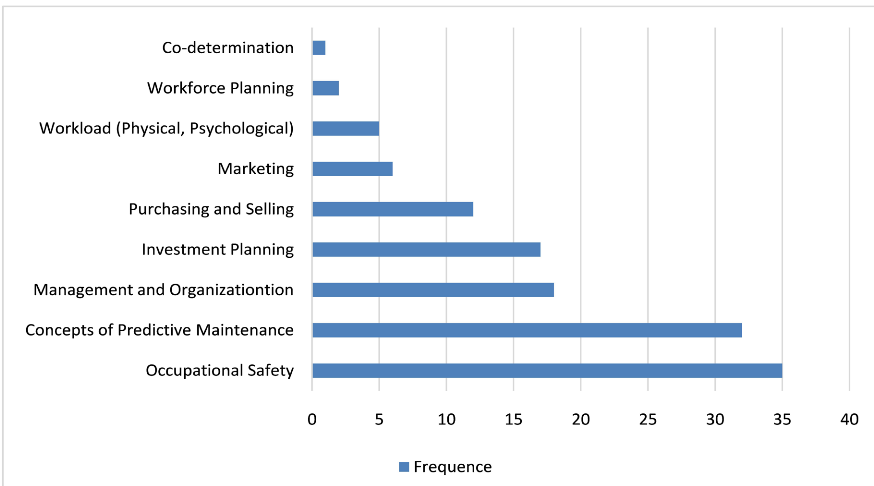

Figure 3. Additional thematic areas.

With eight items (see **Table 4**), competence structure models and teaching and learning methods are depicted. Attitudes towards the sustainable use of digital media in teaching and their added value from the perspective of the respondents were evaluated. The acquisition of vocational action competence was a crucial target in vocational education, especially in practical training at learning factories. Competence structure models of vocational learning (Lindemann, 2015; Sloane, 2005; Dilger and Sloane, 2005) broke down the different areas here.

Table 4. Competence structure models of vocational learning.

Competences	M	SD
Social Competence	2.64	0.98
Professional and Technical Competence	4.33	0.87
Process Competence	3.84	1.13
Personal Competence	2.79	1.15
Language Competence	2.20	1.12
Mathematical Understanding	2.25	1.11
Symbol/Sign and Text Interpretation	2.76	1.13
Methodological Competence	3.42	1.23
Learning Competence	3.49	1.14
Beliefs and Values	2.25	1.25

Scale: 1 = not conveyed at all, 5 = conveyed thoroughly M = mean; SD = standard deviation.

Table 4 illustrates that professional and technical competence, process competence and learning competence were especially crucial in the use of learning factories. The following statements address the sustainable use of digital media in teaching and their added value in Table 5.

Table 5. Use of digital media in teaching and its added value (Gerholz et al., 2022).

Item	M	SD
I carefully consider how, when and why I use digital media in teaching to ensure they are used in a pedagogically meaningful way.	3.77	1.13
I monitor the activity and interaction of my students in the collaborative online environments we use.	2.96	1.18
When students work in groups, they use digital media to acquire and document insights.	3.81	1.19
I use digital media so that students can independently plan, document and reflect on their learning.	3.62	1.28
I use digital media to provide personalised learning opportunities for my students.	3.55	1.29
When working with digital media, I consider possible practical or technical issues faced by my students.	3.72	1.22

Scale: 1 = does not apply at all to 5 = fully applies M = mean; SD = standard deviation.

All areas related to digitality fell within the medium significance range. The use of digital media in teaching appeared to be a component requiring further development. In contrast, there was a significant difference in the personal use of digital media. The use of digital media and tools by teachers (Gerholz et al., 2022), in terms of communication among themselves and professional development, expresses a clearer preference. Further assessments are illustrated in **Table 6**.

Table 6. Use of digital media in teaching and its added value (Gerholz et al., 2022).

Item	M	SD
I systematically use various digital channels to improve communication with students, parents and colleagues.	4.05	1.07
I use digital media to collaborate with colleagues within and outside my educational organisation.	4.08	1.29
I actively develop my digital teaching skills.	4.08	1.07
I participate in online professional development opportunities.	3.67	1.40
I create my own digital resources and modify existing ones to suit my needs.	3.93	0.97
I use various websites and search strategies to find and select different digital resources.	4.13	1.12

Scale: 1 = does not apply at all to 5 = fully applies M = mean; SD = standard deviation.

Digital media were thus used, integrated and shared by the actors. These results were further emphasized in the orientation of the learning factory. Teaching and learning methods were often focused on demonstration (52 mentions) and instruction (37 mentions). In the context of project work, group/partner work on selected case studies or role plays (31 mentions) was central. Blended learning formats (three mentions) or inverted/flipped classroom (four mentions) received little consideration despite the pandemic. Knowledge was predominantly conveyed in alternation with practical phases (36 mentions) or was directly integrated into the practical unit (35 mentions).

Regarding the question of examination, predominantly existing systems, such as knowledge tests (65 mentions), written exams (45 mentions) and oral exams (20 mentions), were mentioned. Nevertheless, practical exercises (39 mentions), self-assessment (19), written assignments (25) and presentations (22) had similar levels.

5. Discussion

This paper reflects on learning spaces and the development of learning factories in vocational education, with the aim of establishing an initial scientific foundation for an exploratory descriptive survey on learning factories. Learning factories are considered promising and methodically complex learning spaces (Leppert, 2021), yet their components and applications have barely been empirically investigated on a broad scale (Windelband et al., 2022). The presented instrument represents a first step towards the gradual description and examination of learning factories in vocational schools. The main part of the questionnaire focused on the design of learning factories, didactic-methodical implementation in the learning process, the process design of the learning factory and the degree of digitalization.

Aspects of school personnel development, especially the recruitment and training of teachers for the use of learning factories, were also examined. A gauge for the achieved level of innovation was cross-departmental in-school collaboration, as well as learning environments with dual partners in the context of the learning factory. This was achieved in the questionnaire through items related to the conditions of the learning factory and additional questions about the dual partners involved in the design and implementation of the learning factories. This also included descriptive parameters such as the company size of the involved partners. In addition, there were several basic questions describing the equipment and conditions of the learning factory. These included self-assessment items (from 1 = completely inadequate to 5 = completely sufficient) for the following fields:

- Spatial equipment of the learning factory
- Technical equipment of the learning factory
- The ability of the learning factory to meet the requirements of Industry 4.0
- Degree of digitization of the institution itself (e.g. vocational school)
- Degree of digitization of the learning factory
- General utilization of the learning factory
- Personnel composition of the learning factory

The presented initial results show how dynamic and heterogeneous the process of implementing learning factories is. Many learning factories are still in their initial phase. New paths are being considered, established ones are being proven and they are being compared with the requirements of the constantly digitizing working world. The surveyed actors in vocational schools quickly encountered formal and substantive limits. The results clearly show that the vocational fields in the context of an Industry 4.0 world are not always reflected. One study participant vividly summarized this: "The use is overall difficult; there is a lack of ideas/concepts. The system is expensive, extensive, and yet has little to do with practice." This statement vividly illustrates that the implementation of a learning factory can represent a significant innovation boost for individual vocational schools (Windelband et al., 2022). However, this success is only achieved if all involved parties share the same goal and are equipped with sufficient resources and competencies. The results suggest that significant conflicts are expected, especially in the conception phase and the initial phase of operating the learning factory. The introduction of a learning factory is a litmus test that questions existing structures and sometimes forces new structures. The necessary factors for successful knowledge transfer highlighted by Rau (2004) and Tynjälä et al. (2021), such as involvement of one's own ideas in task execution, predictability, and experience of control over a situation, also apply to the actors of the learning factory. The requirements posed to and the challenges associated with knowledge transfer in learning factories reveal the complexity of the learning space. This includes the relationship between learning in basic laboratories and learning on the entire system and, thus, actually in the learning factory. The research hypothesis here was that training primarily takes place in the basic laboratories in vocational schools, and it is only successful for a few apprenticeships (e.g. mechatronics) and in technician classes to implement adequately problem-oriented vocational learning situations throughout the entire learning factory. The results confirm the findings of earlier exploratory studies on the use of learning factories in vocational schools in Baden-Württemberg, which were conducted at a very early stage of implementation (e.g. Roll & Ifenthaler, 2020; Scheid, 2018; Windelband, 2023; Zinn, 2014).

An important factor for the success and sustainable integration of the learning factory into everyday vocational life is to integrate it firmly into teacher training and further education. If this succeeds, learning factories can make a significant contribution to vocational education in the technical and commercial professions and in other vocational disciplines. They promote thinking, working, and cooperating in interconnected production systems and have an overview of the entire value-added process.

6. Limitation

The nature of this descriptive exploratory study can be seen as a limitation (Cohen et al., 2018). The lack of fundamental and comprehensive research for the comparison and validation of the initially presented results complicates their classification. Nevertheless, the study represents a first step in categorizing previously neglected areas in vocational learning factories into a larger context. This can only be considered the first point of an emerging project-based research series. The planned follow-up studies will develop and implement an actor-specific questionnaire based on the descriptive results.

The concept of self-assessment by surveyed individuals has been extensively discussed in the research literature (see Cohen et al., 2018; Flick, 2022). Limitations of self-assessment usually revolve around the argument of a lack of control over answers by, for example, superiors or experts in pedagogical-psychological diagnostics. In this context, a series of points used in the survey were mentioned as a solution. These include conducting surveys entirely anonymously, ensuring that participating individuals incur no disadvantage through participation or nonparticipation, considering participating individuals as experts in the treated field and formulating questions that do not allow conclusions about socially desirable answers. Cohen et al. (2018) emphasized that in this context, no method of self-assessment can guarantee absolute truths. However, the meaningfulness of self-assessment questionnaires can be significantly increased with the conscious handling of measurement-theoretical sources of error.

The implementation of a learning factory represents a significant innovation boost for individual vocational schools, which goes well beyond actual technological advancement. It is simultaneously a result and an occasion for a potentially profound social design process within the framework of school development, influencing at least organizational development, personnel, and teaching development, as well as framing internal and external cooperation. However, a significant influencing factor is the technology itself, including the composition of the technical components of the learning factory, the level of digitization of the school and the overall use of digital media (Windelband et al., 2022).

The results of the research on learning factories and the initial descriptive results will be incorporated into the design of a second survey. Validated scales on teaching-learning contexts in vocational education, knowledge transfer and learning factories as innovators in vocational education will be combined with the described set of items for the descriptive classification of processes at a learning factory. At the same time, the circle of vocational schools to be surveyed will be expanded to additional federal states to obtain a comprehensive assessment of the development of vocational schools in the context of the requirements of Industry 4.0 and digitization.

Funding

The article processing charge was funded by the Baden-Württemberg Ministry of Science, Research and Culture and the University of Education Schwäbisch Gmünd in the funding programme Open Access Publishing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abele, E., Metternich, J., & Tisch, M. (2019). Overview on the Content of Existing lEArning Factories. In E. Abele, J. Metternich, & M. Tisch (Eds.), *Learning factories* (pp. 263-287). Springer. https://doi.org/10.1007/978-3-319-92261-4_8

Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H. et al. (2015). Learning Factories for Research, Education, and Training. *Procedia CIRP, 32,* 1-6. https://doi.org/10.1016/j.procir.2015.02.187

Becker, M., Spöttl, G., & Windelband, L. (2017). Berufsprofile für Industrie 4.0 weiterentwickeln. Erkenntnisse aus Deckungsanalysen am Beispiel des Ausbildungsprofils Mechatroniker/-in [Further Developing Occupational Profiles for Industry 4.0. Findings from Coverage Analyses Using the Example of the Mechatronics Technician Training Profile]. *Berufsbildung in Wissenschaft und Praxis (BWP), 46,* 14-18.

Cedefop (2021). *Vocational Education and Training in Germany: Short Description.* Publications Office. http://data.europa.eu/doi/10.2801/329932

Clarke, L., Westerhuis, A., & Winch, C. (2020). Comparative VET European Research since the 1980s: Accommodating Changes in VET Systems and Labour Markets. *Journal of Vocational Education & Training, 73,* 295-315.

https://doi.org/10.1080/13636820.2020.1858938

Cohen, L., Mainion, L., & Morrison, K. (2018). *Research Methods in Education* (8th ed.). Routledge. https://doi.org/10.4324/9781315456539

Dilger, B., & Sloane, P. F. E. (2005). *The Competence Clash—Dilemmata bei der Übertragung des 'Konzepts der nationalen Bildungsstandards' auf die berufliche Bildung [The Competence Clash—Dilemmas in the Transfer of the 'Concept of National Educational Standards' to Vocational Education and Training].* https://www.bwpat.de/ausgabe8/sloane_dilger_bwpat8.shtml

Faßhauer, U., Windelband, L., Mutzke, B., & Harm, S. (2021). *Lernfabriken an beruflichen Schulen als Gegenstand fachdidaktischer Professionalisierung—Entwicklung von standortübergreifenden Medienpaketen im beruflichen Lehramtsstudium [Learning Factories at Vocational Schools as a suBject of Didactic Professionalization—Development of Cross-Location Media Packages in Vocational Teacher Training Courses].* https://www.bwpat.de/ausgabe/40/fasshauer-etal

Flick, U. (2022). *The SAGE Handbook of Qualitative Research Design*. Sage Publication. https://doi.org/10.4135/9781529770278

Frielinck, R. (2023). *Learning Factory Configuration Tool: An Approach for Preserving the Value of Educational Learning Factories.* Master's Thesis, University of Twente. http://essay.utwente.nl/94331/

Gerholz, K.-H., Gillen, J., Faßhauer, U., Bals, T., & Schlottmann, P. (2022). Digitales Unterrichten und Organisieren im Alltag beruflicher Schulen. Eine deutschlandweite Erhebung bei Lehrkräften an beruflichen Schulen. *Bildung & Beruf, No. 1,* 6-13.

Gössling, B., Hagemeier, D., & Sloane, P. F. E. (2020). Berufsbildung 4.0 als didaktische Herausforderung. Zum Umgang von Lehrkräften an berufsbildenden Schulen mit digitalisierten Arbeitswelten [Vocational Education 4.0 as a Didactic Challenge. How Teachers at Vocational Schools Deal with Digitalized Working Environments]. *Zeitschrift für Berufs-und Wirtschaftspädagogik, 115,* 546-566. https://doi.org/10.25162/zbw-2019-0022

Gräßler, I., Pöhler, A., & Pottebaum, J. (2016). Creation of a Learning Factory for Cyber Physical Production Systems. *Procedia CIRP, 54,* 107-112. https://doi.org/10.1016/j.procir.2016.05.063

Harteis, C. (2022). Research on Workplace Learning in Times of Digitalisation. In C. Harteis, D. Gijbels, & E. Kyndt (Eds.), *Research Approaches on Workplace leArning: Insights from a Growing Field* (pp. 415-428). Springer. https://doi.org/10.1007/978-3-030-89582-2_19

Kreß, A., Wuchterl, S., & Metternich, J. (2021). Design Approaches for Learning Factories—Review and Evaluation. In *Proceedings of the Conference on Learning Factories (CLF) 2021*. https://doi.org/10.2139/ssrn.3857880

Lee, E. A., & Seshia, S. A. (2016). *Introduction to Embedded Systems—A Cyber-Physical Systems Approach* (2nd ed.). MIT Press.

Leppert, S. (2021). Prozessmodelle als Grundlage für die Planung von Lernsituationen in komplexen Lehr-Lernarrangements [Process Models as a Basis for Planning Learning Situations in Complex Teaching-Learning Arrangements]. In K. Wilbers & L. Windelband (Eds.), *Lernfabriken an beruflichen Schulen—Gewerblich-technische und kaufmännische Perspektiven* (pp. 49-82). Epubli GmbH.

Lindemann, H. J. (2015). *Kompetenzorientierung. Kompetenzen Beschreiben [Competence Orientation. Describing Competencies].* Dblernen.

Liu, X., Xu, H., Liao, W., & Yu, W. (2019). Reinforcement Learning for Cyber-Physical Systems. In *2019 IEEE International Conference on Industrial Internet (ICII)* (pp.

318-327). IEEE. https://doi.org/10.1109/icii.2019.00063

Löhr-Zeidler, B., Hörner, R., & Heer, J. (2016). Handlungsempfehlungen Industrie 4.0—Umsetzungshilfen für Lehrerinnen und Lehrer der beruflichen Schulen [Industry 4.0 Recommendations for Action—Implementation Aids for Teachers at Vocational Schools]. *Zeitschrift für Theorie-Praxis-Dialog, 70,* 11-14.

McHauser, L., Schmitz, C., & Hammer, M. (2020). Model-Factory-in-a-Box: A Portable Solution That Brings the Complexity of a Real Factory and All the Benefits of Experiential-Learning Environments Directly to Learners in Industry. *Procedia Manufacturing, 45,* 246-252. https://doi.org/10.1016/j.promfg.2020.04.102

Mueller, F. A., Nelles, J., Lacopeta, C., Radermacher, A., & Hammer, M. (2023). Learning Factory Concepts Beyond Capability Building: How a Global Ecosystem of Innovation and Learning Centers Can Guide Technology Innovation and Enable End-to-End Client Impact. In *Proceedings of the 13th Conference on Learning Factories (CLF 2023).* https://doi.org/10.2139/ssrn.4457997

National Science Foundation (NSF) (2016). *"Cyber-Physical Systems," Program Solicitation 16-549, NSF Document Number nsf16549.* https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf16549

Oeben, M., & Klumpp, M. (2021). Transfer of the German Vocational Education and Training System—Success Factors and Hindrances with the Example of Tunisia. *Education Sciences, 11,* Article 247. https://doi.org/10.3390/educsci11050247

Öztürk, E., Hulla, M., Prinz, C., Kuhlenkötter, B., & Ramsauer, C. (2022). Digital Transformation Methods in Learning Factory Based Trainings. In *Proceedings of the 12th Conference on Learning Factories (CLF 2022).* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4072536

Petrusch, N., Briese, C., Lange, A., Oertwig, N., & Kohl, H. (2023). Learning Factory for Circular Economy and the Corporate Environment. In *Proceedings of the 13th Conference on Learning Factories (CLF 2023).* https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4456416

Pilz, M., & Wiemann, K. (2020). Does Dual Training Make the World Go Round? Training Models in German Companies in China, India and Mexico. *Vocations and Learning, 14,* 95-114. https://doi.org/10.1007/s12186-020-09255-z

Rau, R. (2004). Lern- und gesundheitsförderliche Arbeitsgestaltung: Eine empirische Studie [Learning and Health-Promoting Work Design: An Empirical Study]. *Zeitschrift für Arbeits-und Organisationspsychologie A & O, 48,* 181-192. https://doi.org/10.1026/0932-4089.48.4.181

Roll, M., & Ifenthaler, D. (2020). Lernortübergreifende Kompetenzentwicklung in der Industrie 4.0: Die Entwicklung digitaler Handlungskompetenz in der dualen Berufsausbildung aus der Ausbilderperspektive [Competence Development across Learning Venues in Industry 4.0: The Development of Digital Skills in Dual Vocational Training from the Trainer's Perspective]. In C. Aprea, V. Sappa, & R. Tenberg (Eds.), *Zeitschrift für Berufs- und Wirtschaftspädagogik—Beihefte, Beiheft 29* (pp. 185-209). Franz Steiner Verlag.

Scheid, R. (2018). Learning Factories in Vocational Schools: Challenges for Designing and Implementing Learning Factories at Vocational Schools. In D. Ifenthaler (Ed.), *Digital Workplace Learning: Bridging Formal and Informal Learning with Digital Technologies* (pp. 271-289). Springer. https://doi.org/10.1007/978-3-319-46215-8_15

Sloane, P. F. E. (2005). Kompetenzen und Kompetenzniveaus in der beruflichen Domäne von Wirtschaft und Verwaltung: Bildungsstandards, Kompetenzorientierung und Lernfelder [Competences and Competence Levels in the Vocational Domain of Business and Administration: Educational Standards, Competence Orientation and Learning Fields]. In Verband der Lehrerinnen und Lehrer an Wirtschaftsschulen, Landesverband NRW e.V. (Hrsg.), *Bildungsstandards für die berufliche Bildung II. Handlungserfordernisse. Dokumentation der 2. Tagung vom 17. Januar 2005 in Duisburg*. Düsseldorf.

Soori, M., Arezoo, B., & Dastres, R. (2023). Internet of Things for Smart Factories in Industry 4.0, a Review. *Internet of Things and Cyber-Physical Systems, 3,* 192-204. https://doi.org/10.1016/j.iotcps.2023.04.006

Sudhoff, M. (2021). Lernfabriken an Hochschulen—Bestandsaufnahme [Learning Factories at Universities—Stocktaking]. In R. G. Heinze, D. Kreimeier, & M. Wannöffel (Eds.), *Lernfabriken an Hochschulen: Neue Lernorte auf dem Vormarsch? Bestandsaufnahme-Curriculare Ausrichtungen-Transferkanäle* (pp. 16-37). Hans-Böckler-Stiftung.

Thiede, S., Juraschek, M., & Herrmann, C. (2016). Implementing Cyber-Physical Production Systems in Learning Factories. *Procedia CIRP, 54,* 7-12. https://doi.org/10.1016/j.procir.2016.04.098

Tynjälä, P., Virtanen, A., Virolainen, M. H., & Heikkinen, H. L. T. (2021). Learning at the Interface of Higher Education and Work Experiences of Students, Teachers and Workplace Partners. In E. Kyndt, S. Beausaert, & I. Zitter (Eds.), *Developing Connectivity between Education and Work* (pp. 76-96). Routledge. https://doi.org/10.4324/9781003091219-7

Weyand, A., Lehnert, S., Alish, V., & Weigold, M. (2023). Approach for the Implementation of Resource Analysis Methods in Learning Factories. *Production & Manufacturing Research, 11,* Article ID: 2209152. https://doi.org/10.1080/21693277.2023.2209152

Wilbers, K., & Windelband, L. (2021). Vorwort [Preface]. In K. Wilbers, & L. Win=delband (Eds.), *Lernfabriken an beruflichen Schulen—Gewerblich-technische und kaufmännische Perspektiven* (pp. 5-13). Epubli GmbH.

Windelband, L. (2023). Lernfabriken in der beruflichen Bildung—Möglichkeiten für die beruflich Fachrichtung Metalltechnik [Learning Factories in Vocational Training—Possibilities for the Vocational Specialization of Metal Technology]. In A. Grimm, & V. Herkner (Eds.), *Entwicklungen und Herausforderungen der beruflichen Fachrichtung Metalltechnik und deren Didaktik* (pp. 227-244). Peter Lang.

Windelband, L., Faßhauer, U., & Anselmann, S. (2022). Potenziale von Lernfabriken für die berufliche Lehrkräftebildung—Konzepte und Erprobungen in Baden-Württemberg [The Potential of Learning Factories for Vocational Teacher Training—Concepts and Trials in Baden-Württemberg]. In K. H. Gerholz, P. Schlottmann, P. Slepcevic-Zach, & M. Stock (Eds.), *Digital Literacy in der beruflichen Lehrerinnen- und Lehrerbildung* (pp. 57-70). Wbv Media.

Zinn, B. (2014). Lernen in aufwändigen technischen Real-Lernumgebungen—eine Bestandsaufnahme zu berufsschulischen Lernfabriken [Learning in Complex Technical Real-Life Learning Environments—A Review of Vocational School Learning Factories]. *Die berufsbildende Schule, 66,* 23-26.

Zitter, I., Beausaert, S., & Kyndt, E. (2021). On Principles for Connectivity between Education and Work. In E. Kyndt, S. Beausaert, & I. Zitter (Eds.), *Developing Connectivity between Education and Work* (pp. 230-236). Routledge. https://doi.org/10.4324/9781003091219-16