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Learning factories at vocational schools

Industrial-technical and commercial perspectives

Karl Wilbers and Lars Windelband (eds.)

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Uwe Faßhauer, Karl Wilbers & Lars Windelband

Learning Factories: A Future Model for Vocational Education?

The article explains the emergence of learning factories in practical engineering education and the subsequent use in in-company training. The current use at vocational schools is outlined, the concept of the learning factory for vocational education is specified and the technical-didactic orientations are described. The design of the interplay between industrial-technical and commercial [illegible] is a current field of learning factories at vocational schools. Finally, current challenges for the further development of learning factories are elaborated and discussed.

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This article looks at learning factories from their origins and fields of application in the academic field of engineering education to their current use in vocational education, predominantly at vocational schools. The interplay of industrial-technical and commercial activities in the context of the use of learning factories and the benefits for vocational training are examined more intensively.

Symposium "Learning Factories" - Graphic Recording of the Impulses from Science

1 Learning factories in academic, corporate and school education: history and current use

Learning factories are used in universities, companies and vocational schools. They have a different history, different areas of application and a different orientation in these institutions.

1.1 Learning factories in academic education

In medical education, teaching hospitals have the task of providing students with practical experience in addition to theoretical specialised teaching. The concept of learning factories takes up this idea for other areas of academic education.

The term "learning factory" was first coined in 1994 by a project funded by Penn State University. The goal was an interdisciplinary, practical high-school education of engineers with strong cooperation with in-dustrial companies (Tisch 2018, 44). Since its inception, 1,200 sponsored design projects have been carried out based on real problem situations from different companies. In 2006, this project won the Gordon Prize of the National Academy of Engineering (La- mancusa et al. 2008).

In Europe and in Germany, the first ideas for the implementation of a learning factory emerged around the turn of the millennium, specifically in the years 2004 to 2007 in Darmstadt. In 2007, the first learning factory in Germany was officially opened in Darmstadt at the Institute of Production Management, Technology and Machine Tools (PTW) of the Technical University of Darmstadt in cooperation with companies (Bosch, SEW). With the support of Germany, curricula were developed quickly and the first pilot trainings were carried out (cf. Process Learning Factory 2020). The learning factory was continuously developed in terms of its equipment and possibilities. It was the first learning factory in Germany to map the complete value stream from raw materials to machining and assembly to shipping (Abele et al. 2007).

Other university learning factories will follow, such as at the Ruhr University in Bochum and the Technical University in Munich. Focus of the Bochum learning factory opened in 2009 are lean production, Industry 4.0 and resource management. The Lean Production Learning Factory (LSP) at the Technical University of Munich is a modular system that supports various manufacturing processes (Abele et al. 2010).

Learning factories are used at universities for university teaching and further education, but also for research. According to the International Academy for Production Technology (CIRP), a learning factory for teaching and further education is defined by (Abele et al. 2015, 2):

- Processes that are authentic, include several stations and both technical and organisational aspects,
- a changeable environment that corresponds to a real value chain,
- a physical product that is manufactured, and
- a didactic concept that enables formal, informal and non-formal learning on site through the active participation of the learners.

The target groups at universities are primarily students from production- or logistics-related Master's and Bachelor's degree programmes who can gain experience in a real production environment with the help of learning factories.

Learning factories usually integrate a variety of different teaching methods, whereby action-oriented learning in production, i.e. task-specific problem solving in a realistic learning environment, represents the unique selling point of the learning factory learning system (Abele et al. 2015, 20). Learning factories aim to teach interdisciplinary skills (see Bianchi-Weinand and Wannöffel in this volume).

In the real or virtual production environment, test runs, experiments or problem-oriented questions can be carried out on various issues relating to technologies, organisational problems and the role of people, which are part of university education.

A new target group are students of vocational and business education who are prepared for the work of learning factories in vocational education. For this group of students, both the subject-specific and the didactic perspectives are relevant. New here are the questions about the design of learning processes and the question of for conditions for successful learning in the context of learning factories in the vocational teaching profession. The locations of the University of Teacher Education Schwäbisch Gmünd and the University of Erlangen-Nuremberg have already implemented this in their study programmes.

Learning factories, especially at universities, often have a research purpose in addition to the purpose of education and training. Scientific and practice-relevant topics such as the design and control of efficient production or logistics systems are worked on there. Production, quality control, assembly, packaging, logistics and indirect processes are often simulated in a real operating situation and conclusions are drawn for the design of learning processes. This distinguishes a learning factory from a model factory. According to Wannöffel & Bianchi-Weinand (2018, 6f.), learning factories link basic research, applied research and experimental developments. Current topics in research on learning factories often address a range of socio-technical sys- tems in the area of tension between people, technology and organisation (cf. Abele et al. 2015, 12). There are many intersections between these levels, which have increased in the context of developments towards Industry 4.0 with a higher level of system networking. Current research questions are:

- Improvement of the production and/or logistics process: lean production, lean management, just-in-time production.
- Reconfigurability: factory virtualisation, digital production planning, simulation of production systems, information systems for planning and control.
- Energy and resource efficiency: energy and resource consumption, optimisation strategies, measurement technologies.
- Human-machine design: assistance and learning systems, working conditions and work processes, design of workplaces, problem-solving processes, role of the human being.
- Networking the production world: testing new Industry 4.0 technologies, CPS systems, use of data analyses for transparency and optimisation, integration of intelligent production machines.
- Competence development: staff competences, learning strategies, learning forms and learning media.

In addition, the close-to-reality reproduction of production with reduced complexity and at the same time significantly lower costs means that tests can be carried out, e.g. for learning with digital me-

The learning factories can be used to check the results in relation to successful learning with the respective test persons. Here, learning factories can be used to check the results obtained in relation to successful learning with the respective test persons. Theoretical approaches can thus be applied in practice in a realistic production environment with less time and financial risk. This enables an accelerated development process (Abele et al. 2019, 249 f.).

Learning factories for the purpose of education and for the purpose of research and development cannot be clearly separated. The newly acquired knowledge can thus lead to new individual or scientific questions. For the new questions that arise, theoretical knowledge must in turn be acquired and reviewed (cf. Wannöffel & Bianchi-Weinand 2018). With regard to higher education institutions, learning factories thus open up a new form of scientific and experiential orientation in which cognitive and constructivist learning theory approaches can promote professional action competence (cf. ibid.).

1.2 Learning factories in company-based further training

Learning factories at universities are also used for in-company training. The further training of skilled workers at the skilled worker level, engineers but also employees of other occupational groups on different topics within the learning factories,
The training of employees, including for lean production, is another field for the learning factories at universities. Here there are offers for vocational training and further education for companies, offers for their own employees or also for external persons.

For some years now, more and more companies have also been using in-house learning factories for the training and further education of their employees. Well-known examples are the MPS learning platform of Daimler AG (since 2011) with a focus on lean production and the Festo learning factory in Scharnhausen (since 2014) of Festo AG with four different topics, namely mechanical processing, valve assembly, automation and process optimisation and administration of the learning factory (cf. Abele et al. 2019). In the last decade, more and more learning factories have thus been developed in Germany and in Europe with a wide variety of focal points and for a wide variety of application areas.

Demonstrators, which have a high similarity to learning factories, are used in companies to support transformation and development processes (see contribution by Oks et al. in this volume). This is about ensuring participation and co-determination and integrative stakeholder-centred procedures of system development, which should also ensure the acceptance of new digital procedures.

Companies are also partners in the learning factories of other institutions. Particularly in Baden-Württemberg, the learning factories at vocational schools funded by the state must offer co-operations and further training with regional small and medium-sized enterprises (SMEs) in order to meet the funding conditions. The learning factories are often used for further training in the topics of digitalised production and various issues of Industry 4.0. They are often also used as a starting point for change management. The motivational aspects of the learning factory are particularly important (Abele et al. 2019, 234 f.).

1.3 Learning factories at vocational schools

The history of learning factories in VET is difficult to describe, as smaller learning factories have existed for many years. They were usually called "learning factories", more often "learning labs". Moreover, they typically covered only single aspects of a complex production chain.

Since 2016, different initiatives for the promotion of vocational learning factories can be seen in Germany, namely at the state level. Particularly noteworthy are the funding initiatives in Baden-Württemberg (see Barthruff et al. contribution in this volume), in Bavaria (see Lucha and Weiß contribution in this volume) and Lower Saxony (see Fre- richs contribution in this volume). All three funding initiatives also focus on an interplay between commercial-technical and commercial activities.

Figure 1: Conference "Learning Factories" - Graphic Recording of the Virtual Roundtable

The first learning factories at vocational schools were, among others, the Learning Factory 4.0 at the Gewerbliche Schule in Göppingen, the Smart Factory facility at the Berufsbildende Schulen Osnabrück Brinkstraße (see Sayk's contribution in this volume) and the Industry 4.0 bottling plant at the Be- rufsbildende Schulen 2 in Wolfsburg. Statistical data on the areas of application of learning factories in vocational schools in Germany are not available. However, learning factories are likely to be used primarily in technical schools and in initial vocational training.

Fachschulen are vocational schools for continuing vocational education and training. They follow on from initial vocational training and professional experience in various forms of teaching organisation (full-time or part-time). The competence expectations in the vocational school are - measured by the German Qualifications Framework - at the same level as Bachelor's degree programmes in academic education. Against this background, the use of learning factories at Fachschulen has many parallels to learning factories at universities. When implementing learning factories at vocational schools - especially at bundled schools - learning factories are therefore an important bridgehead.

Dual vocational education and training is a much larger segment of vocational education and training than technical schools. For a few years now, more and more learning factories have been used at the vocational school as a learning location in dual vocational training. The aim here is to teach students vocational skills in the context of the developments towards Industry 4.0 with the change in working conditions. Currently, learning factories focus on industrial-technical vocational training, namely around the topics and occupational fields of automation technology, electrical engineering, metal technology, mechatronics and control engineering.

The high technical complexity of production processes in the context of Industry 4.0 goes hand in hand with the high demands on the technical understanding of learners and teachers. In order to be able to understand the work and business processes in the context of Industry 4.0, skilled workers in the industrial-technical and increasingly also the commercial occupational fields are confronted with this process understanding.

For commercial education, work with learning factories is still relatively new. The development here is currently taking place mainly as a cooperation between a commercial and a technical school. In this volume, the cooperation of the vocational school 2 and the vocational school 4 of the city of Nuremberg (see contribution Klose et al. in this volume), the Hubert-Sternberg-Schule and the Johann-Philipp-Bronner-Schule in Wiesloch (see contribution Frötschner and Heeger in this volume) as well as the vocational school I & II in Kemp- ten (see contribution Eldracher, Ferdinand and Hehberger in this volume) are presented as examples. Also conceivable is the cooperation of the commercial and the industrial-technical sector in a bundled school as in the case of the vocational school centre in Amberg (see Greiner and Pongratz in this volume). An exception is the cooperation of two bundled schools, as in the case of the vocational school centre Lorenz-Kaim-Schule in Kronach and the state vocational school Lichtenfels (see Schirmer, Lichy and Meisinger in this volume).

2 Learning factories at vocational schools: Defining terms, technical and didactic concepts

2.1 Conceptual Clarification

The term "learning factory" is used in different ways. The learning factory should make it possible to imagine a working context in which real working conditions are simulated for learners. It is a complex, demanding, spatial and didactic-methodical conceptualisation (cf. Zinn 2014). The term "learning factory" stands for a teaching-learning environment based on technical and methodological principles, which ideally represents the entire production process and adjacent company areas (Steffen et al. 2013). Taking into account definitions in vocational education and training (Zinn 2014, 23), the term learning factory can be defined as follows:

Learning factories are defined here as simulations which, in a modular structure with the help of flexibly usable current technical components with high but varying degrees of reactivity, depict socio-technical systems of industrial production of physical products and support vocational teaching and learning, especially with learning situations, for the acquisition of technical but also personal competences.

From a didactic point of view, working with learning factories is a simulation: teaching and learning can be understood as a three-step process of briefing, acting with a model and debriefing, and in addition to learning in the model, learning on the model must also be taken into account. Learning factories thus have parallels to other simulations in the commercial field, such as work in training companies, but also to technical simulations, such as robot simulations (Wilbers 2020, 453 ff.).

The learning factory must be flexible in its use. Different combinations of production planning and situations in the sense of company case studies can be presented (cf. Zinn 2014, 23).

Learning factories consist of current technical components. Learning factories have a high but varying degree of reality. The degree of reality of a learning factory is represented by the presence or lack of machinery, equipment and devices. At these conditions, the teaching of vocational action competences is only possible according to the current state of the art (cf. ibid., 23).

Learning factories model socio-technical systems, which means that the model action must not be limited to the technical system, but must refer to both the technical system and the social system. With regard to the social system, on the one hand it is about the cooperation of people, also of different professions, but also about different strategies of design, i.e. value creation or work organisation.

Learning factories offer great potential for achieving a high degree of orientation to professional actions through the simulation of real work and business processes. The prerequisites for this are a high degree of topicality of the learning factories in relation to the software and hardware, variability in the system design and composition in order to depict different scenarios for problem orientation and the highest possible degree of realism in the action situations. The basis for this is knowledge of current professional situations in the world of work. In order to be able to use the potential of the learning factory, the scenarios must aim to promote independent organisation and problem-solving skills in the trainees (ibid., 23).

2.2 Technical concepts for learning factories

Learning factories were defined here as simulations that reproduce socio-technical systems of industrial production of physical products in a modular structure with the help of flexibly usable current technical components. Several strategies can be distinguished in the composition of the technical components.

- In-house production or outsourcing: In principle, the learning factory can be outsourced. Large manufacturers of teaching materials now offer a wide range of products. Schools can create learning factories themselves - also as a school development project. Self-production offers opportunities, but also risks (see the article by Pongratz and Greiner in this volume). Learning factories can be configured in different ways.
- Industrial components or non-industrial components: Some learning factories use only industrial components, others do not. A mixed form is conceivable. Whether a configuration consisting exclusively of non-industrial components can still be called a learning factory in the above sense is debatable. This category mainly includes combinations of elements from construction kit systems such as fischertechnik or Lego Technic.

- Cyber-physical components or virtual technical components: Industrial production processes in Industry 4.0 are characterised by the integration of cyber-physical systems. This corresponds to the construction of a learning factory from physical and virtual elements. Purely virtual working or learning tools that are used to simulate industrial processes are not understood here as learning factories in the above sense.

2.3 Didactic concepts for learning factories: Three levels

A three-level model can be used to describe the general didactic-methodical orientation. According to this, three levels can be distinguished, namely the learning factory level, i.e. the level of the learning factory as a whole, the learning module level and the learning situation level. On these levels, the structure and framework conditions of the learning factory, the general orientation and classification of the learning modules, as well as the concrete implementation of the learning situation with the specific objectives can be mapped. This leads to the fact that there is no uniform didactic concept for learning factories, but that the parameters differ depending on the orientation, objective and target group.

(a) According to Tisch (2018, 74), the learning factory **level** focuses on the socio-technical learning factory infrastructure including the production and logistics environment, the machining processes, the networking of the production steps with the relevant data and interface points within the process chain, the product to be manufactured as well as the role and tasks of the employees, the content framework of the learning factory programme to be designed with the linking of the ERP system and MES system as well as a basic didactic concept. This is strongly dependent on the structure and objective of the learning factory, i.e. is the learning factory a demonstration plant, does the learning factory serve to display processes or does it focus on professional issues for employees at the shop floor level or employees at the level of commercial work.

(b) At the **learning module level,** the focus is on the design of the learning module. Within the learning environment of a learning factory, different learning modules are often integrated. These can be linked to each other, or they can be designed independently of each other in terms of thematic orientation or with regard to specific target groups. The design of a learning module includes the sequencing of learning processes and situations as well as the planning of changeability in the socio-technical infrastructure of the learning factory (ibid., 75). The choice of topics in learning factories varies greatly, as the example of

Learning factories in universities show: From material flow design and optimisation (Lernfabrik Universität Darmstadt[1]), Actors 4.0: Business game for the digital future (Future Work Lap in Stuttgart[2]) or resource efficiency in lean production (Ruhr Universität Bochum[3]). The thematic orientation often focuses on engineering aspects (universities) or technical aspects (companies or vocational schools). In times of increasing digitalisation of the world of work and the associated networking of entire processes along the entire value chain, not only manufacturing and production processes are important in the selection of topics, but also areas of factory planning and intralogistics, commercial processes and the organisation of work. The topics for the learning modules are expanded to include labour policy aspects such as co-determination or the design of the human-machine interface to promote learning. At vocational schools, the learning module of a learning factory is integrated into a learning field, which can be assigned to a specific training occupation.

(c) The **learning situation level** focuses on the level of learning situations that are arranged in learning fields or modules.

Common to all three levels is the focus on work and business processes. Each learning factory sets up its own didactic concept in order to be oriented towards the respective target groups. Thus, learning factories at universities are consequently primarily tailored to students, but also to the needs of academic staff (cf. IG Metall 2018). In contrast, learning factories at vocational schools focus on trainees and thus on the skilled work level with learning in vocational action situations. The resulting learning and competency goals are curricularly specified in the corresponding learning fields of the respective training occupations for the vocational school part.

The goal of a learning factory in the context of Industry 4.0 is to enable learners to work competently in complex contexts and to simulate work process-related tasks with thinking and acting in networked production (cf. Windelband & Faßhauer 2016). For this, suitable learning environments must be created and a didactic concept for knowledge transfer must exist. In order to ensure this, the following didactic criteria must be observed (Zinn 2014, 23):

[1] https://www.prozesslernfabrik.de/ (as of 20.10.2020)
[2] https://futureworklab.de/ (as of 20.10.2020)
[3] https://www. lps.ruhr-uni-bochum.de/lernfabrik/index.html (as of 20.10.2020)

- Problem-oriented teaching and learning processes are based on concrete professional situations.
- Problem-solving skills must be able to be developed in experience-led work situations.
- Work organisation and dealing with planning strategies become learning principles.
- Self-organisation and self-responsible group learning form the core idea of an action-oriented learning environment.

2.4 Deepening: Learning situations in Learning factories

Learning situations are characterised by competence expectations, a central action pro- duct, an action process, an action space and an action process, which provide for a certain teaching action within a given framework of conditions (Wilbers 2020, 483 ff.).

The **competency expectations** focussed on in learning factories basically emphasise manual competence and problem-solving skills. The overarching learning objectives in the learning factory include independent planning as well as carrying out and controlling work activities according to the model of complete action. In vocational schools, the main goal is to enable trainees and students of the vocational school to acquire or deepen vocational action competence. For this reason, all learning factories at vocational schools are structured in a problem- and activity-oriented manner and their content is aligned with the corresponding learning fields of the framework curricula.

The aim is to learn in a way that is as process-oriented as possible through problem-oriented action and thus close to the actual work and business processes. Aspects of networking and thinking in networked systems can be closely linked to this. In particular, the further merging of information technology with classical production processes can be addressed here using real tasks. In addition, independent and continuous learning, informal competences in abstract thinking and communication as well as problem-solving skills are promoted as important abilities in a working world 4.0 in the learning factory.

Due to the current developments in the context of Industry 4.0, the complexity and networking within practical plants is constantly increasing, which is why analytical skills are becoming even more important for the industrial-technical professions (cf. Zinke et al. 2017; bayme vbm 2016). These complex interdependencies along the entire word creation chain are not easy to grasp mentally. Therefore, a learning environment is necessary that reflects them as accurately as possible in order to be able to train effectively (Lütjens 2006, 3). In addition to the core Industrie 4.0 content (sensory/actuator technology, flexible manufacturing, networking, etc.), the learning factories currently being introduced offer the opportunity to gain a deeper understanding of the interrelationships within the value chain. In a learning factory, the entire value chain and thus the entire order processing from the ordering of a product, the planning process, the ordering of the necessary materials, the material supply, the production and processing steps up to the quality control and the delivery of the product (to the customer) can be mapped.

The learning situations thus include essential elements of an action-oriented qualification such as work and business process orientation, reflection on theory and practice, science and experience orientation (cf. Wannöffel & Bianchi-Weinand 2018). Many of the learning factories have a modular structure, so that the value-added process (often as a production process) is structured in several stages, e.g. in the form of a processing of production steps and an assembly unit with integrated functions of logistics and quality assurance. The modular structure in the equipment enables forms of optimisation so that the learners can not only show concrete improvements in the process chains but also actively implement them. This means that theoretical knowledge can be applied directly in a "real" production and logistics environment.

A central basis for the delimitation of the competence expectations is the implicit model or the explicit model of the processes underlying the learning factory. The procedures of process-oriented subject analysis (see Leppert's contribution in this volume) are suitable for explaining the process model. The contributions in this volume on the learning factories in Amberg (see Greiner & Pongratz), in Nuremberg (see Klose & Siegert), in Kempten (see Eldracher, Ferdinand & Hehberger), in Kronach-Lichtenfels (see Schirmer, Lichy and Meisinger) and in Wiesloch (see Frötschner & Heeger) show concrete examples of process models underlying learning factories. In addition, process models in vocational schools - as the example in Osnabrück (see Sayk in this volume) shows - can not only be the basis for subject analysis, but also the object of learning.

Many learning factories that are currently being set up at vocational schools with a focus on Industry 4.0 have a two-stage didactic concept:

1. On the one hand, this is the **basic laboratory,** which provides the trainees with an introduction to digitally controlled production technologies. In various basic modules, questions of modern industrial production are taught (including sensor/actuator technology, identification technologies, communication architecture, MES and database systems).
2. The second stage is the actual **learning factory** (Smart Factory) with a linking of all focal points from the basic laboratories to form a holistic learning factory. Here, the trainees have the opportunity to train intelligent production processes on the basis of real industrial standards, to control networked processes themselves and to solve concrete professional problem situations.

Across all levels, the focal points of "Industry 4.0" are built up in a modular and object-oriented way in order to be able to realise flexible manufacturing systems and thus concrete professional action situations. This means that the learning factory can be flexibly adapted and expanded at any time and also kept open for future products, tasks and technologies. This is particularly important because the developments towards Industry 4.0 are only just beginning and will continue to evolve (Windelband 2019, 40).

Products of action are generally the result of individual phases of the complete action and the product of action of the implementation phase represents the central product of action (Wilbers 2020, 483 ff.). The action product of the learning factory is therefore not the central physical product that is manufactured within the learning factory. Rather, the action products of the individual phases must be differentiated with the help of the model of the complete action.

The **process of action** is designed differently within the framework of learning situations in learning factories. A learning situation in a learning factory can have an exploratory, experimental, systematising, reflective or problem-solving character. In learning factories, practice- and action-oriented approaches, which originate primarily from vocational education, are thus integrated into academic forms of learning. The learning objects have a concrete situational reference and are oriented towards real vocational tasks, often with a high problem orientation for vocational education. The learners can go through their learning processes partly self-organised, depending on the objective.

Learning factories offer great potential here, as qualification can be very work process-oriented and close to real professional practice. This is particularly successful if the learning factory reflects the current state of development in practice, i.e. the plant is state of the art. At the same time, vocational action situations at the plant must be be realisable. From the installation of a sensor in the system to concrete predictive maintenance, for example, occupational action situations can be depicted and modified.

Further elements for the design of learning situations are the learning methods used (e.g. business game, project, demonstration, instruction, fault diagnosis, production task), the learning materials used (from worksheets to a VR tour of the plant), the learning media used (digital and networked media for simulation, visualisation by means of a digital twin, communication and collaboration) and the result as a learning product (from a basic understanding of Industrie 4.0 to concrete maintenance activities for a specific occupational group at the plant) (cf. Fig. 2).

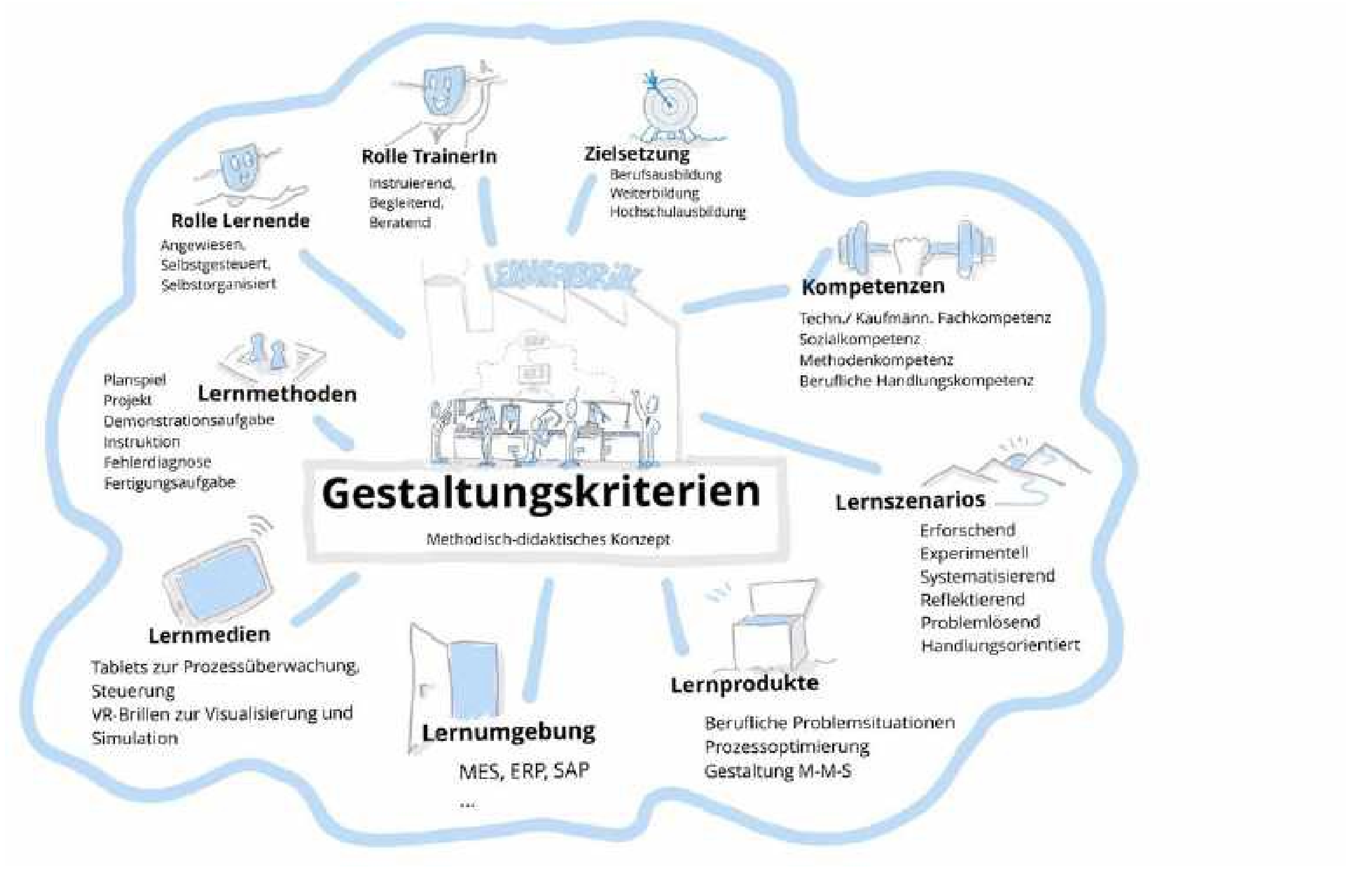

Figure 2: Design criteria of methodological-didactic concepts in learning factories

During the action process, learners also use **media.** Here, for example, accompanying also tablets are used for process monitoring or VR glasses for visualisation and simulation.

The accompanying **teaching action or the role of the teacher** is demanding. In learning factories, the acquisition of knowledge and competences often takes place in a process that is actively built up by the learner, but can also take place through instruction. Accordingly, the teaching action varies and provides for both instructing, accompanying or advising activities.

3 The design of the interplay between commercial-technical and commercial education in learning-factories

3.1 The interaction of MES and ERP system as a possibility space

The technical linking of the ERP system with the MES creates an opportunity for the combination of industrial-technical and commercial education, which is exploited in different ways. The Enterprise Resource Planning System (ERP) manages the entire factory from the customer's order to delivery, and the Manufacturing Execution System (MES) regulates the production processes with all the necessary manufacturing and assembly steps.

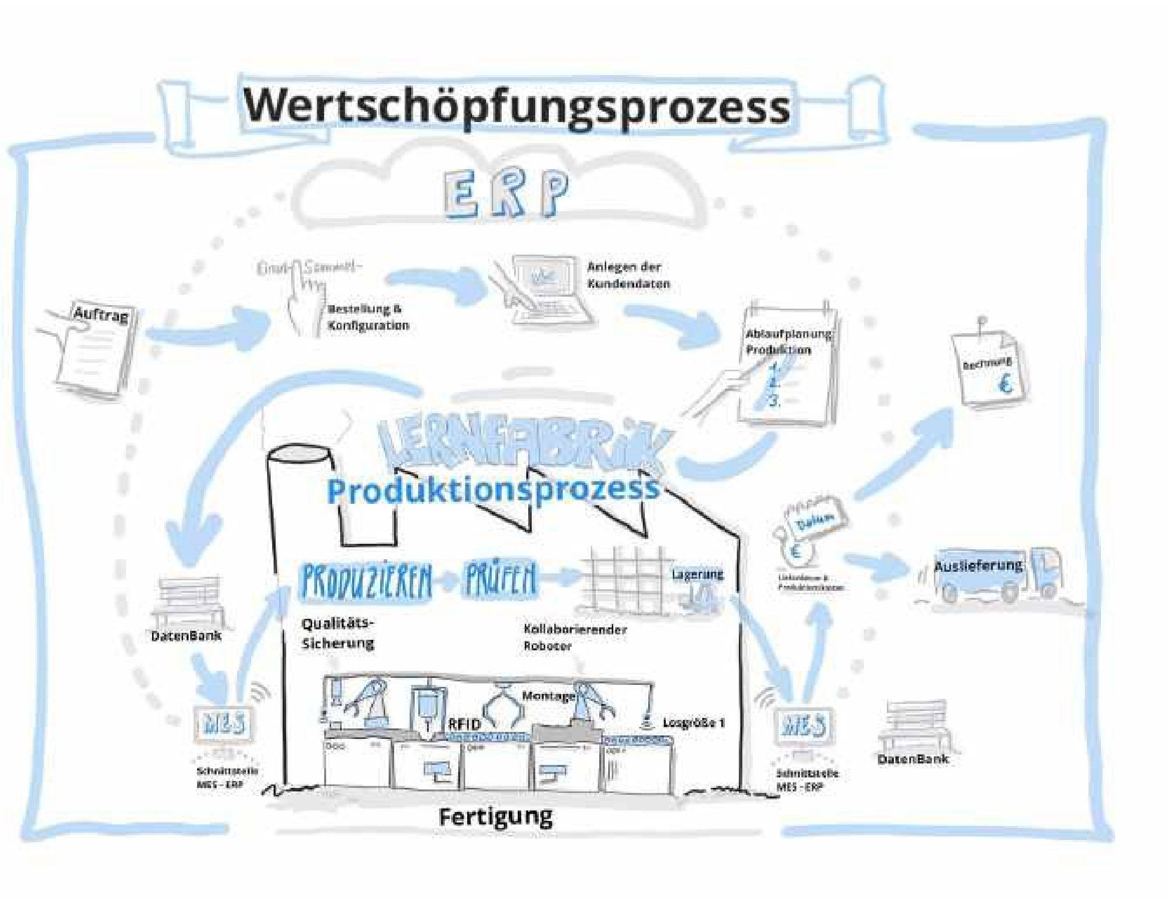

Figure 3: MES and ERP in the interaction between industrial-technical and commercial vocational training

The central point in a learning factory is a manufactured physical product (cf. Figure 3), which can often be produced in different versions. The aim of the Learning Factory 4.0 is to manufacture with a batch size of one at the direct request of the customer.

On the business side, it is first of all about the business processes in the value creation process, i.e. to be able to show and implement the chain of tasks with all possibilities between order receipt up to the delivery of the product with the help of the ERP system. An important point here is the interface between the ERP system with the order and the production control with the ME system. Production, assembly, quality monitoring and the integration of logistics in the interlinked machine system are the next steps that are controlled via the MES. In the process, IT and business data are directly linked to each other and the data is passed on as close to real time as possible and automated. Likewise, the

The production process can also be changed during the production process in order to be able to implement individual solutions or short-term customer requests.

This is clearly illustrated by the example of the Learning Factory 4.0 in Bietigheim-Bissingen (Dröge et al. 2018, 129f.):

- The MES computer controls the individual orders through the plant and communicates continuously with the PLC, which coordinates the individual process modules. The MES computer receives the production orders from an intermediate database to which both the MES computer and the ERP system have read and write access. The production progress and the assembly success are reported by the MES computer back to the ERP system. The material stocks are automatically updated there according to material consumption.
- The orders are divided into series production and special production. In series production, several model cars of the same type are assembled. The serial number of the model car is stored on the RFID chip and tracked on the assembly line. In special production, all assembly-relevant data is stored on the RFID chip. The VMS (interlinked machine system) controls itself on the basis of this data. The MES computer merely compares the order number with the ERP system, always according to the principle of "no production without an order".

Only a timely overview of all relevant and available data/information within the value chain, the planned status in the overall process and the availability of the necessary resources allows an optimised organisation as well as a flexible reaction to changes such as a new order situation or disruptions in the system.

It must be ensured that the trainees within a smart factory (here the learning factory), whether in the planning area, in logistics, in the production area or in service, receive the relevant information prepared and presented in a suitable form so that they can also use this information/data for the respective work task. This gives the interaction between different professions a whole new meaning.

Networking with other occupational groups, especially commercial occupations, is increasingly emerging as a future task for the didactic concepts of learning factories in initial and continuing vocational education and training. This becomes particularly clear at the interface between the Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP). However, didactic challenges exist here in order to achieve a closer link in the learning settings.

3.2 Necessity of promoting systemic thinking in the work with learning lab- rics

The links between commercial and industrial-technical activities (Wilbers 2019) must not be limited to the forwarding of data and information between the ERP and MES systems, but an overall understanding of the business process, i.e. a comprehensive understanding of the process, should be developed, as various studies also call for in the context of Industry 4.0 developments for vocational education and training (cf. Zinke et al. 2017; Pfeiffer et al. 2016, Ittermann & Niehaus 2018; bayme vbm 2016).

The demands from the world of work clearly show that the skilled workers of the future will need a stronger process and network thinking. The fact that reality still has quite a way to go here is shown by Schmid's (2018, 31) statement: "The system concept must be placed more at the centre of training. This is still done too rarely in vocational schools and training today. Industry 4.0 always involves working with small technical units with an identical image in the programme, which interact and communicate with other systems via interfaces. This kind of thinking has to become part of people's minds. In this context, interdisciplinary links, concrete didactic concepts to promote holistic thinking in process interrelationships and thinking in networked systems must be placed more at the centre of training. In practice, there is still a clear separation between the individual occupations and occupational groups in vocational schools and training companies.

3.3 Levels of interaction between industrial-technical and commercial education in learning-factories

The common frame of reference for industrial-technical and commercial education are work and business processes. The (re)construction and design of the work and business processes underlying the learning factory work thus offers a starting point for the development of this interplay. One method for this is process-oriented factual analysis (see Leppert's contribution in this volume).

The first stage of development of the interplay between commercial-technical and business activities concentrates on the realisation of the make process, especially in the commercial-technical area. From the point of view of models for work and business processes

The SCOR model or the classification of management, business and support processes (Wilbers, 2020, 44 ff.) show that the work in learning factories concentrates on the "make" process of a physical product, i.e. a real good. This more or less complex make process forms the core of every learning factory, so to speak. The illustration of a more or less extensive make process in a learning factory is elaborate and can enable great progress from a didactic point of view by looking at the process as a whole. Upstream and downstream processes, such as the purchasing process (source) or the return process (return) are not yet considered in this core model. This also applies to management and support processes or plan and enable processes. The "make" process is the starting point of every learning factory, but offers hardly any possibles for the interaction of commercial and industrial-technical activities. In a narrower sense, there is no interaction between commercial-technical and commercial activities at this stage. For the design of the interaction, however, a broadening and/or deepening of the process is required at the next level.

In a *process extension,* the typical make process for learning factories is extended by upstream or downstream processes. The generation of an order in the commercial domain before the make process, but also the invoicing after the make process, plays a central role. Such a broadening of processes results in a potential for the interaction of commercial and industrial-technical activities. This is reflected in the interaction of ERP and MES. From a didactic point of view, this process broadening leads to sequence dependencies in the sense of the theory of cooperative learning (Wilbers 2020, 434 ff.) (Green & Green 2009, 77 ff.). Such dependency occurs when the contributions of one group member or subgroup must be made in order for another group member to make their contributions. This cooperation leads to clearly defined handover points, although the potential for cooperation is present but limited.

In a *process deepening,* the typical make process for learning factories is extended by "plan" and "plan" processes.

"Enable" processes in the sense of the SCOR model. The focus on operational tasks in production is no longer necessary. These processes run partly in parallel or within the make process. In didactic terms, this deepening of processes in the sense of the theory of cooperative learning (Wilbers 2020, 434 ff.) leads to resource dependencies (Green & Green 2009, 77 ff.). A resource dependency exists when each member or sub-group is can only contribute a part of the competences, information, materials, etc. that are necessary to cope with the overall task. A typical example is the creation of a more complex proposal that relies on data from a design or production simulation. Examples that can be found in current learning factories, which are described in the contributors of the schools in this volume, are mainly the generation of a quotation in interaction with the design or a production proposal, the production simulation, the release of a production order, but also enable tasks such as quality or process management.

The broadening of processes, but also the deepening of processes in particular, offers extensive possibilities for shaping the cooperation between commercial and industrial-technical activities (Wilbers 2019). Taking into account the difference between commercial-technical and commercial action (Wilbers 2020, 87 ff.), the commercial relevance of learning factories increases with a stronger accentuation of (1) nominal goods processes, (2) information processes that serve the control of real and nominal goods flows, (3) processes of reflection of nominal value creation and (4) commercial application systems.

From the perspective of digitalisation, Industry 4.0 and artificial intelligence, it is striking that the typical transformation to hybrid products, i.e. the combination of material products with immaterial products, is not depicted. In addition, accounting in current learning factory approaches still seems to be strongly characterised by a traditional understanding of accounting. Automation of commercial processes with the help of machine learning, repercussions of accounting on the process organisation, new business models such as platforms with new key figures, for example the conversion rate, but also the use of artificial intelligence or new visualisation techniques still seem to play a subordinate role (Wilbers 2021). However, these would be possible for the further development of learning factories in order to further exploit the potentials and to better link the value creation processes.

4 Learning factories at vocational schools: Current challenges

Based on the literature and current development work in vocational schools, current challenges for further work can be derived. At the network event "Learning Factories: Industrial-technical and commercial perspectives" a number of challenges were developed in exchange and discussion. At the network event, evaluation, school development, technical challenges, resources, didactics and personnel development were presented as current challenges.

Figure 4: Symposium "Learning Factories" - Graphic Recording of Challenges and Perspectives

4.1 Didactic design of Learning factories

A "didactics of the learning factory" on the three levels mentioned is still emerging. Convincing scientifically based concepts for determining the competence requirements relevant in learning factories, for recording the existing competences of learners in learning factories and for the development of competences in learning factories, including the promotion of the transfer of the acquired competences into the reality of companies, are only available in parts. Furthermore, examination concepts need to be adapted to the work in learning factories.

4.2 School and network development and technical challenges

Especially in the case of learning factories, it seems necessary to embed this change in equipment systemically in a comprehensive change project. The facilities follow the logic of industrial processes with an enormous complexity, which leads to considerable demands on staff development in the school and thus bears the risk of insularity - also within the school. The use of learning factories should not be limited to small parts of vocational education, especially training in M+E professions as well as technician schools. The facilities are mostly so expensive that a comprehensive provision for all vocational schools does not seem realistic and alternative provision strategies or strategies of cooperation have to be developed. In addition, the question of sustainable financing arises in view of the changes in industrial processes.

A particular technical challenge is the technical integration of ERP and MES. This leads not only to a lack of broad impact, but also to the fact that interesting application scenarios for Industry 4.0 - such as the partial joint training of industrial clerks and industrial mechanics - are made more difficult. The existing technical components seem to differ greatly from each other - scientific surveys are lacking. This raises the question of the possibilities and limits of standardising learning factories.

4.3 Qualification of teachers and training staff

The qualification of teachers in the different phases and of the training staff is a considerable challenge. It is associated with high didactic and technical demands. The great diversity of the learning factories makes the training and further training of teachers and their support - for example in the form of handouts - considerably more difficult. The concepts for the further training of teachers differ greatly between the federal states. In higher education, this plays almost no role.

The staff in vocational schools, i.e. the vocational school teachers, often lack subject-specific knowledge because they are less and less familiar with current professional practice and the changes in a digitalised world of work. As a result, they have difficulties in presenting the interrelationships in a learning factory and in depicting the complex issues of the networked world of work in the smart factory. For the sustainable operation of

Learning factories therefore require a model that not only considers the continuous financial aspect, but also ensures human and thematic sustainability (cf. Abele et al. 2016).

Only a few teachers are currently integrated in the implementation of learning factories at vocational schools (cf. chapter 4). As a result, often only a few training occupations are integrated in the learning factory. In order to expand the areas of application of the learning factories, teachers must receive further training and be appropriately qualified. First offers have been launched in the federal states (see articles by Lucha & Weis; Barthruff et al.; Frerichs in this volume).

4.4 Resources and sustainability of Learning factories

The planning, development, construction and operation of learning factories require financial and human resources. Especially the financial aspect is a major challenge for many learning factories. Many learning factories can only be realised if they are supported by the state or by companies. Companies that support learning factories are usually in close cooperation with the learning factories, so that they can also benefit from them, e.g. in order to be able to carry out further training for their employees. One problem, which at the same time represents a challenge for the learning factory, is the costs incurred for the operation and continued use of a learning factory. Due to the premise that learning factories must continue to develop, new costs are also incurred for new technologies, equipment and maintenance (cf. Windelband & Faßhauer 2016).

Learning factories can often only represent a limited section of production environments due to the space available. An exact representation of reality is accordingly limited. The learning factories have to concentrate on certain topics and take important process steps that take place before or after as given. For example, limits arise in the commercial processes, since the ordering of materials or the sale of products can often only be simulated. Another point that arises in the modelling of the learning factory is the logistical effort. Learning factories need sufficient space to map realistic production, which is not available in many locations or must first be created. In order for the learning factory concept to be profitable, there should be a high demand for appropriate training within the learning factory.

be available. However, this would require staff or teachers who are involved in the normal running of the school.

4.5 Evaluation of Learning Factories

Learning factories are run with the aim of developing learners' competences. However, it is often not verified whether the learning approaches are effective. This is also a problem of learning factories. In order to achieve effective learning factories, learning outcomes must be taken into account both in the design phase and in the evaluation phase (cf. Abele et al. 2016). There are not yet any scientific results for vocational education and training to be able to make statements about when a learning factory is successful. In view of the different orientations of learning factories and the various financial models ranging from approx. 6,000 euros to 1 million euros, answers here would support the further development of learning factories in vocational education and training. So far, there is a lack of scientific accompanying programmes that can support the development of vocational learning factories.

5Outlook:Learning place cooperative development of Learning factories

The learning factories should represent a realistic or didactically reduced representation of production processes in a learning environment. The challenge is to depict the complex world of work realistically and still be able to generate problem-related tasks that contain learning content. "The systems are so complex in their structure that currently only a few teachers can work with them." (Schmid 2018, 32). So far, only a few teachers have actually dealt with the construction, realisation and implementation of learning factories in general and their integration into the classroom in concrete terms. Here, it is important to involve as many training professions and teachers at vocational schools as possible. The integration of training companies into the issue of the learning factory has only been successful in individual cases so far, the potential for dual vocational training - but also for continuing vocational education and training, e.g. in technical schools - has not yet been realised.

One example of successful cooperation is the so-called Knowledge Network Kronach-Lichenthels (see Schirmer, Lichy and Meisinger in this volume). As an example, reference can also be made to a learning situation developed cooperatively at the learning location, which was developed and tested within the framework of a project financed by the Baden-Württemberg Ministry of Economics.

The aim of one of three dual sub-projects was to combine a learning factory of a vocational school (TS Aalen) with the "Smart Factory" system of the Carl Zeiss AG company to form a cooperative learning project. For this purpose, the existing basic module of the learning factory (CP Lap-Station Drilling) had to be upgraded for the acquisition of performance and consumption data. The installation of the necessary sensor technology and the visualisation of the consumption flows recorded for pre-dictive maintenance (remote maintenance beyond other locations) were largely implemented independently by the trainees. Subsequently, these skills were transferred to the "Smart Factory" plant of the training company. The parameters obtained are used to simulate remote maintenance. Thus, both learning factories were linked to simulate production at several locations and their monitoring. The data transfer and evaluation are cloud-based, the corresponding connection of the acquired measurement data etc. was another goal of the project between the two dual partners (Faßhauer & Windelband 2020).

The joint development and testing of didactic concepts in cooperative learning locations has resulted in a non-formal qualification of the educational staff. The project was able to show that the didactic requirements in the context of Industry 4.0 can be designed in the - albeit time-consuming - learning location cooperation. Cross-learning location issues that have process competence with thinking and acting in networks at their core can be integrated into training. Understanding the process interrelationships with all upstream and downstream areas within the networked production systems and being able to assess their educational and qualifying effect will be less and less achievable by just one learning location.

However, the model project also shows how difficult cooperation is between the learners and within the different vocational specialisations at a vocational school, as all institutions have little freedom to test and redesign (digitised) learning processes with a high level of process orientation. If this freedom is lacking, then the change towards VET 4.0 with a changed learning culture will not be possible.

It seems to be indisputable that a functioning learning location cooperation is helpful for the implementation of the complex learning carrier "learning factory". However, will the developments in the context of the implementation of "Industry 4.0" in general and the implementation of learning factories at vocational schools in particular lead to more frequent and/or more intensive learning site cooperation on the micro and meso level?

In previous decades, too, more or less sudden ("disruptive") introductions of new technologies and processes have repeatedly led to profound changes in vocational training. For example, the comparatively rapid penetration of CNC (Computerised Numerical Control), CAD/CAM (Computer Aided Design/Computer-Aided Manufacturing) or CIM (Computer Integrated Manufacturing) technologies in industrial companies in the 1980s, which ultimately led to a reorganisation of occupations and the implementation of action orientation. A similar caesura can possibly be observed with the establishment of new quality management concepts in the 1990s, which certainly resulted in a strong impulse for a further reorganisation of the M+E professions as well as the introduction of process orientation in training and learning fields at vocational schools. However, the current profound development through digitalisation does not only affect the M+E professions but practically all vocational disciplines and sectors at the same time and also the commercial ones, as was shown not least in the context of the symposium.

Therefore, longer-term impulses for learning location cooperation at the meso and micro levels can be expected. So far, there are hardly any elaborated concepts for the didactic design of vocational learning processes for the understanding of networked work and business processes in production and services. Rather, these are only being developed with regard to specific needs across occupations and places of learning. The necessary technical and didactic know-how is not available in its entirety at individual learning venues and makes cooperation between companies and vocational schools seem particularly necessary.

At least the ambitious and often well-equipped vocational schools are now playing a more active role. This should lead to companies, especially SMEs, having a stronger interest in a didactically sound cooperation between learning venues at the meso and micro levels.

Whether this learning site cooperation itself can now also be essentially digitalised and effectively used to generate didactic innovations - and thus be placed in the analogy of "4.0" developments - is to be seen much more positively than a few years ago under the impression of the rapid developments in the course of pandemic management (Faß- hauer 2018). The joint development, testing and evaluation of didactic and curri- cular innovation by teaching and training staff is an expression of a high intensity of learning site cooperation. Rarely institutionalised and often informal as joint in-service training, it has a certain tradition, but remains rather marginal and selective. However, for (at least) two decades, information technologies, virtual communication and work platforms as well as approaches to knowledge management and networking have been jointly tested, evaluated and also used on a day-to-day basis by teachers from both learning venues as support structures at the meso and micro levels. Their effectiveness in improving cooperation between learning venues is strongly dependent on the respective benefit expectations of the actors and the level of cooperation achieved so far. In the context of learning factories, this - additional - form of learning location cooperation would be appropriate, helpful and, not least from the point of view of SMEs, very attractive in order to be able to use innovations in the context of learning factories for the own further development of the company.

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