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# Learning Factories for research, education, and training

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**Abstract**

In the last decade, numerous learning factories for education, training, and research have been built up in industry and academia. In recent years learning factory initiatives were elevated from a local to a European and then to a worldwide level. In 2014 the CIRP Collaborative Working Group (CWG) on Learning Factories enables a lively exchange on the topic "Learning Factories for future oriented research and education in manufacturing". In this paper results of discussions inside the CWG are presented. First, what is meant by the term Learning Factory is outlined. Second, based on the definition a description model (morphology) for learning factories is presented. The morphology covers the most relevant characteristics and features of learning factories in seven dimensions. Third, following the morphology the actual variance of learning factory manifestations is shown in six learning factory application scenarios from industrial training over education to research. Finally, future prospects of the learning factory concept are presented.


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*Keywords:* learning factory; morphology; education; vocational training, competency development

## 1. Motivation

Industry's urgent challenges are ranging from the integration of new technologies (currently in particular the transition to ad hoc networked, real-time, adaptive, decentralized and self-optimizing Cyber-Physical-Production Systems) over demographic change to volatile business environments in general. In order to survive companies need to be able to quickly adapt to new market conditions. This ability of the company is highly dependent on the ability of employees on all hierarchy levels to act self-organized in unknown situations and to find creative solutions [1,2]. For developing employees' competencies for manufacturing environments, traditional teaching methods show limited effects [3]. Therefore, new learning approaches are needed

- that allow training in realistic manufacturing environments
- that modernize the learning process and bring it closer to the industrial practice
- that leverage industrial practice through the adoption of new manufacturing knowledge and technology
- that boost innovation in manufacturing by improving capabilities of young engineers, e.g. problem solving capability, creativity or systems thinking capability – talent based innovation is the number one driver of manufacturing competitiveness [4].

Universities and training facilities are confronted with the challenge to identify future job profiles and correlated competence requirements and they have to adapt and enhance their education concepts. Especially, innovative learning environments have to be able to react on above mentioned challenges. Industry now demands interdisciplinary training, which underlines the already proven education and training in learning factories.


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## 2. History of learning factories

In 1994, the National Science Foundation (NSF) in USA awarded a consortium led by Penn State University a grant to develop a “learning factory”. This is when the term was first coined and patented. It referred to interdisciplinary hands-on senior engineering design projects with strong links and interactions with industry. A college-wide infrastructure and a 2000 square meters facility equipped with machines, materials and tools was established and utilized to support hundreds of industry-sponsored design projects since 1995. This program was recognized nationally and received the National Academy of Engineering’s Gordon Prize for Innovation in Engineering Education in 2006. This early model of learning factories emphasizes the hands-on experience gained by applying knowledge learned at the culmination of engineering education to solve real problems in industry and design/re-design products to satisfy identified needs [5–7].

More recently the use of learning factories has increased, particularly in Europe, and has taken many forms of facilities varying in size and sophistication aiming to enhance the learning experience of trainees in one or more areas of knowledge. In the last years numerous learning factories have been built up [8,9]. The Institute of Production Management, Technology and Machine Tools (TU Darmstadt) had one of the early learning factory implementations of this new wave in 2007. Two real products are produced in a complete value stream from raw materials to the shipped products. Also several other learning factories with other foci and physical manifestations were built up in this time. The broad variety of learning factories is shown in section 5 of this paper.

With the establishment of the Initiative on European Learning Factories in 2011 at the "1st Conference on Learning Factories" in Darmstadt the topic “learning factory” took a next step to joint collaboration throughout Europe. In 2014, additionally a CIRP Collaborative Working Group on learning factories was initiated in order to establish a joint understanding of relevant terms surrounding action-oriented learning and learning factories, to gather knowledge of the global state-of-the-art, and to generate input for further research programs and collaboration models.

## 3. Terminology and definition of learning factories

In order to find a common understanding of the term ”learning factory”, inside the CIRP Collaborative Working Group on learning factories various existing definitions of “learning factories” and “teaching factories” were collected, analyzed, and compared in order to extract dominant key features in all definitions, see also Fig. 2. Numerous discussions inside the CIRP community lead to joint understanding of learning factories in the narrow and learning factories in the broader sense.

The label “learning factory” with the composition of the two words “learning” and “factory” is to be used for systems that address both parts of the term – it should include elements of learning or teaching as well as a production environment [8]. The word “learning” in the term, as opposed to teaching, emphasizes the importance of experiential learning where research has shown that learning by doing leads to greater retention and application possibilities than traditional methods such as lectures, see e.g. [3].

Learning factories provide a reality-conform production environment as a learning environment where only minor abstractions are possible. This means processes and technologies inside the learning factory are based on real industrial sites. In learning factories not only single workplaces or machines, but changeable multilink value added chains are available, which enable a direct approach to different phases of the product creation process [9–11]. Trainees can discover and test approaches or conduct experiments in this environment on technological and organizational industry-related issues [12–14].

The main goals of learning factories are either

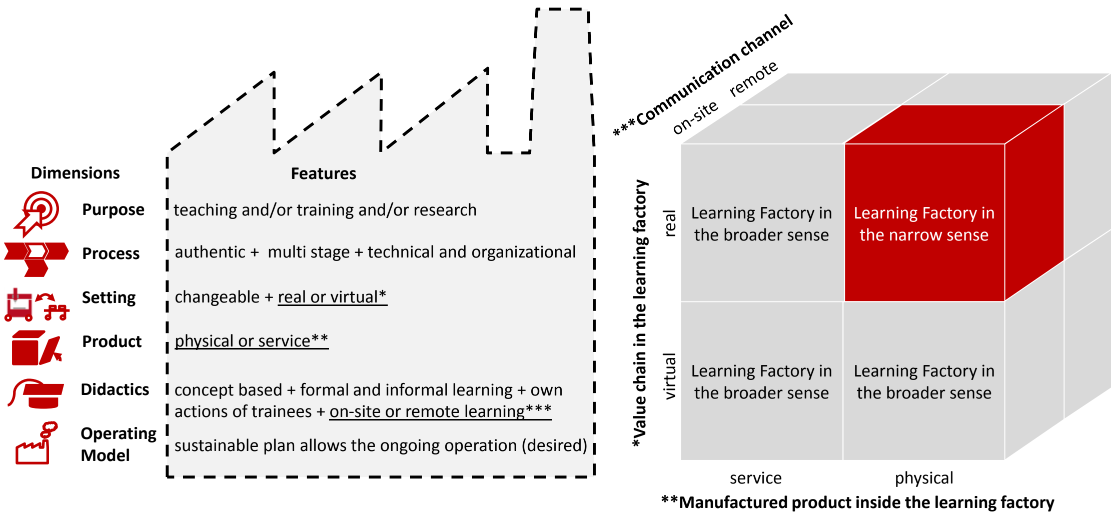


Fig. 1: Key features of learning factories and distinction between learning factories in the narrow (red cube) and in the broader sense (all grey fields)

technological and/or organizational innovation (if used for research), or an effective competency development (if used for education and training), i.e. the development of the participants' ability (including motivational and emotional aspects) to master complex, unfamiliar situations, see for example [10–17]. Therefore, a didactic concept that specifies what and how should be learned by whom is an indisputable part of a learning factory. Learning in the learning factory can either take place in the planning, realization, and ramp-up phase (greenfield) but also in the improvement of existing processes and factory environments (brownfield).

The learning factory concept is implementable in a lot of different ways. In order to achieve effective competency development the core of the learning factory concept is a high degree of contextualization (close to real factory environments) and a hands-on experience of the trainees. Some of the learning factory variations fit these core concepts better than others. According to this, learning factories in the broader sense are further away from reality and less hands-on but offer advantages regarding the scalability, the location-independent use, or a widened scope of addressed problems.

The learning factory in the narrow sense provides a real value chain for a physical product in which participants can perform, evaluate, and reflect their own actions in an on-site learning approach.

The learning factory in the broader sense modifies this concept in at least one of the following directions:

a) Virtual representations of value added chains [18–20].
b) The connection of the trainees to the learning processes based on remote ICT connections [21].
c) The "product" of the learning factory is a service.

Learning factories create values in augmenting the capacities of today's and tomorrow's factory personnel along the value chain over all hierarchy levels in various technological and organizational fields of action. In order to not only built-up, but also continuously operate and improve the learning factory, created values have to be linked with a sustainable business model.

## 4. Morphology of learning factories

As shown in the definition of "learning factories" there is a broad range of learning factory configurations. Characterizing single facilities and comparing those with one another is greatly facilitated by description models. In recent years, several description models for that purpose have been published [8–10,22]. They all use the heuristic procedure of morphologic analysis to achieve a delineation of learning factories.

Major advantage of the morphologic analysis as a tool for describing the complex system of a learning factory is the inclusion of all relevant features and characteristics and their potential attributes [23]. Thus, a picture of learning factories both holistic and generic can be drawn while at the same time a particular learning factory can be classified, allowing a simplified illustration of the correlations between all existing options to conceptualize a learning factory and the specific design of the actual learning factory that is being analyzed.

As learning factories are developing further continuously, initiated for example through socio-technological megatrends or findings from education research, also description models need to be adapted or even extended constantly. Therefore, the CIRP CWG on learning factories as well as the consortia project Network of Innovative Learning Factories (NIL), which is funded by German Federal Ministry of Education and Research through the German Academic Exchange Service

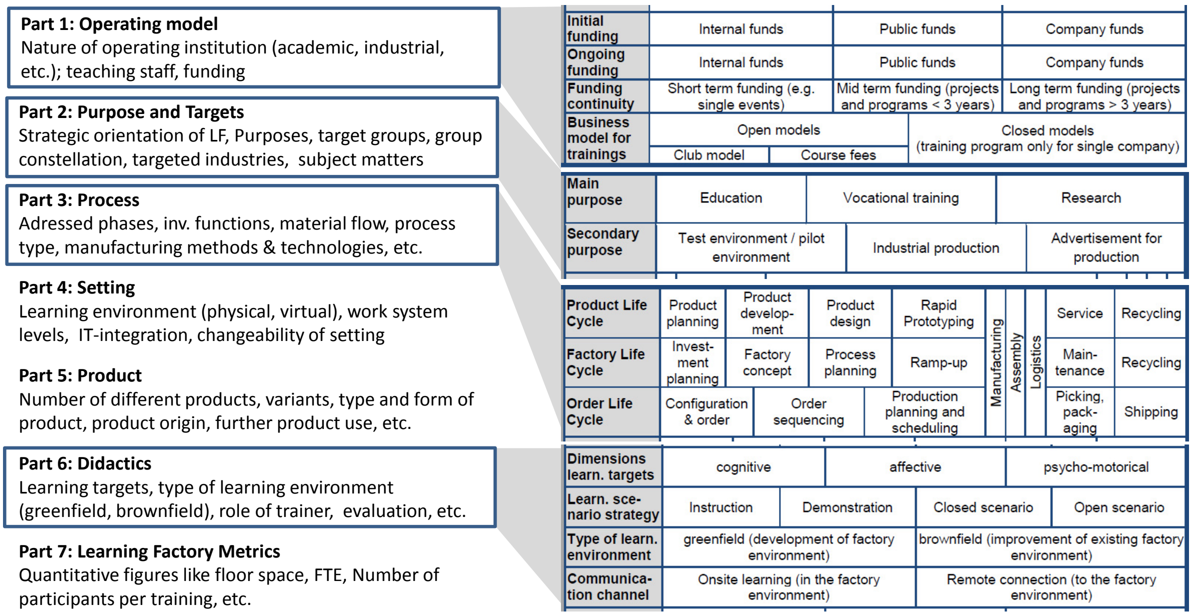


Fig. 2: Selection of specific learning factory features of the seven parts of the morphology

(DAAD), simultaneously developed and validated a multi-dimensional description model. It can serve as an orientation in the design of a new learning factory as well as a classification tool for existing learning factories at the same time. For the description model presented here, more than 50 single features in seven dimensions were identified before elaborating the respective attributes for each. As a next step, an online platform will be provided in order to gather data from learning factories worldwide and to facilitate overviewing the broad and diverse range of existing facilities.

## 5. Variety of learning factories

As shown in the previous sections the term “learning factory” covers a wide variety of learning environments regarding various dimensions. No learning factory usually resembles another or is used in the same way. In order to give insights into various embodiments of the learning factory concept, in the following section different learning factory application scenarios are described. Figure 4 describes the respective application scenarios regarding selected features from the morphology presented in section 4. The scenarios do not represent the complete range manifestations, among others, for example a scenario where an industrial company is the operator is missing. In industry, most notably large automotive companies have recognized the enormous potential of learning factories.

### *5.1. Learning Factory I: Industrial application scenario*

In the past, it has been shown that a small number of companies able to increase its value for customers and employees through process orientation and the use of methods of lean production significantly. However, most companies could not achieve this success. The difference was not in the methods used, but successful companies have managed to develop their employees at all hierarchy levels in order to

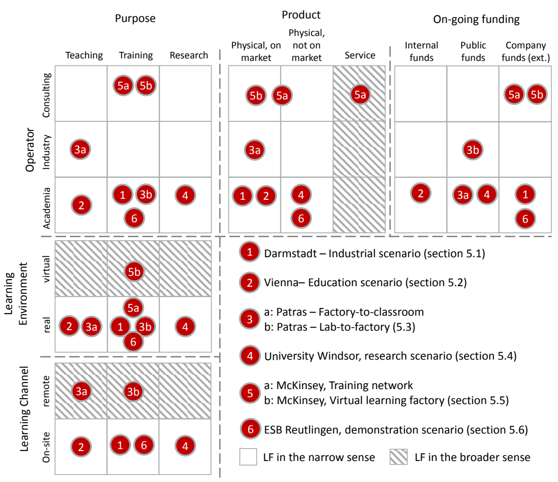

Fig. 3: Application scenarios of section 5 regarding selected characteristics derived from the morphology of section 4

facilitate the application of newly acquired skills and competences. Learning factories are suitable environments that enable companies and students to acquire the competence to boost sustainable productivity.

The Process Learning Factory CiP forms a training environment with over 500 square meters realistic production environment in which all areas of industrial production are addressed. In the two machining lines with nine machine tools and the two subsequent assembly lines, two real products are produced. These are, on the one hand a pneumatic cylinder with a single-digit number of variants and a gear motor from SEW with more than 4000 variants. In this way it is ensured that the different requirements of industrial trainees are fulfilled. The Process Learning Factory CiP opened its doors in 2007 and was since then used in research, education as well as in the training of industrial employees, which is described in detail in the following paragraphs.

In the Process Learning Factory CiP industrial participants can discover lean principles and methods and apply them directly on problems in a real production environment without risk of failure or cost pressure. Due to the real production conditions the transfer of problem solving abilities from the training to the own company is facilitated. Multiday workshops with approximately 10-15 participants take either place in form of standardized trainings (annual training cycle) but also customized trainings.

Approximately 20 CiP-partner companies (with a wide range from the process industry over one-off to serial production) develop their employees from top management to the line level in learning factory workshops of the annual training cycle. The 15 standardized workshops are divided in three phases: Lean Understanding and Basics, Lean Core Elements, and Lean-Culture.

In addition to this offer, in customized workshops the content of trainings is geared to specific requirements of the customer. In this way, learning factory trainings support companies for example in the course of a lean transformation with individually designed training modules in order to support change processes.

### *5.2. Learning Factory II: Academic application scenario*

In Vienna, the TU Wien Learning and Innovation Factory for integrative production education represents the physical educational platform for an activity-based course to give students the real experience and a broad understanding of the integrative product emergence process [24]. That includes steps like product planning and design, engineering, manufacturing, assembly as well as quality assurance. The hands-on training consists of an exercise to analyze, plan, build and optimize a real product, a slotcar, and its production process. Different didactical approaches are used, especially blended learning, the combination of online self-learning, frontal teaching and hands-on training in the learning team [11].

In 2011, the TU Wien Learning and Innovation Factory was initiated, developed and operated by three institutes of TU

Wien in cooperation with Fraunhofer Austria. Currently, it is used primarily for higher and advanced education. In 2013 the project team committed to integrate key aspects of "human centered cyber-physical production systems" (HCCPPS) into the learning factory successively, to react on the challenges of the upcoming future production scenario Industrie 4.0.

Thus, for the academic education a proper understanding of engineering as well as computer sciences at the same time is essential. The classic production job profile like the industrial engineer increasingly has to dive into the world of information and communications technology. IT skills are needed to be able to cope with the modeling of complex processes and the cross-domain integration of different systems [25].

Students do not only apply but also have to configure different interfaces of the used IT-components, the factory planning software and other tools, like the MES- and ERP-System, to bridge and consolidate unequal data sources and files in a robust and reliant way.

With these learning elements, the TU Wien Learning and Innovation Factory aims at an educational concept that illustrates students the complexity of the interconnection of the virtual, digital and real world to strengthen especially the systems and interface competence.

### *5.3. Learning Factory III: Remote learning scenario*

The Teaching Factory concept is based on the knowledge triangle notion aiming to seamlessly integrate its cornerstones education, research, and innovation [21,26]. It has its origins in the paradigm of the teaching hospitals, namely the medical schools operating in parallel with hospitals.

The Teaching Factory has emerged as a promising paradigm for integrating the factory environment with the classroom. It is a non-geographically anchored learning space, which is facilitated by advanced ICTs and high-grade industrial didactic equipment. The communication and interaction of remotely located teams of engineers and students/researchers, working on real-life problems and engaging actual facilities at the industrial and academic sites is enabled. On that basis it operates as a bi-directional knowledge communication channel bringing the real factory to the classroom and the academic lab to the factory [27].

The "factory-to-classroom" knowledge communication channel aims at transferring the real manufacturing environment to the classroom. The real life manufacturing site has to be used for teaching purposes in order to enhance the teaching activity with knowledge, existing in the processes of every day industrial practice. Students in the classroom act as the knowledge "receivers". On the industrial company side, engineers introduce and present real shop floor problems and engage the students in problem solving activities.

The "lab-to-factory" knowledge communication channel of the Teaching Factory aims to transfer knowledge from academia to industry. Engineers at an industrial site act as the knowledge "receivers". Industrial-grade or didactic equipment installed into the academic facilities can be used as test-beds and demonstrators for new technological concepts to be validated by students and researchers. The technology and knowledge can be then transmitted back to industry either for support in the decision making processes, or for introducing an engineering or management team to the new concept or solution.

The Teaching Factory remote learning scenario has been successfully validated in the context of *KNOW-FACT*, a Knowledge Alliance project funded by EC DG Education [28]. The proof-of concept has been delivered on the basis of pilot cases that engaged academic institutions and industrial companies [29].

### *5.4. Learning Factory IV: Changeability research scenario*

The integrated systems-oriented type of learning factories was set up in 2011 at the Intelligent Manufacturing Systems Centre at the University of Windsor - a first iFactory in North America [30]. The transformable production platform (iFactory) includes modules that can be easily reconfigured to change the system layout and its functionality. It consists of advanced modules for assembly and inspection. The learning factory focuses on systems learning which integrates products design, customization and personalization. The iOrder module is integrated with innovative physical and logical enablers of change such as variant-oriented re-configurable process and production plans through the iPlan module, and manufacturing systems design synthesis, layout complexity and optimum system granularity.

### *5.5. Learning Factory V: Consultancy application scenario*

In the consulting business learning factories are used very similar to the industrial application scenario presented in section 5.1. The global consulting company McKinsey for example established learning factories with experiential learning for capability building in various fields of application and different branches. Figure 7 gives an overview over the global McKinsey learning factory network. Additionally, McKinsey also implemented the idea of a new "Virtual Model Factory" for better scalability and mobility of the learning factory concept [31].

### *5.6. Learning Factory VI: Demonstration scenario*

The industrial equipment available in the ESB Logistics


Fig. 4: McKinsey learning factory network, according to [31]

learning factory serves as an ideal environment for the demonstration of future production scenarios' fundamental ideas. A one-day demonstration has been designed specifically for SMEs and non-industrial stakeholders like financial institutes that wish to get a basic understanding of the functional interaction between the human workers, automation solutions and information and communication technology in a linked production environment. The assembly and logistics system of the learning factory, which includes six assembly workstations, supermarket racks and several conveyors, have therefore been upgraded to a higher technological degree of maturity (RFID-transponders, Pick-by-light, robot supported assembly processes, additive manufacturing technologies). The night before the workshop, participants may order customized scale-models of a solar-powered cyclist through an online shop. Most required components are manufactured additively over-night. The next day, participants assemble their desired product at the learning factory. Thus, participants, who are in general no production professionals, receive an introduction about data consistency from product design through manufacturing to assembly, about the potential of ICT for decentralized production and logistics control and how smart factory equipment supports flexibility while relieving instead of replacing the human factor in state-of-the-art production.

## 6. Future prospects for learning factories

Today, learning factories already cover wide range application scenarios. In the future it will be important, that effective and efficient learning factory configurations can be identified and developed systematically. To do this, it is fundamental to be able to measure learning success in a simple but valid way. Regarding the learning processes innovations are desirable: learning factories have to enable individual learning paths for training participants, also virtual or media-supported and remote trainings can boost the scalability of learning factory approaches. Learning factories should be closer linked with innovations (new prototypes and product technologies, production technologies and processes, e.g. the development of CPPS). In order to further develop the possibilities of learning factories the numerous partners should continue to share their ideas in networks for good learning factory practices regarding education, training, and research.

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