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A systematic approach on developing action-oriented, competency-based Learning Factories

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Abstract

As a next challenge, in terms of enhancing employees' improvement abilities with the use of Learning Factories, existing education and training programs are remodeled by the means of a competency-oriented, scientific-founded didactic concept. Therefore, based on a multi-level study on Learning Factories focusing on their design and use, a systematic approach to further develop quasi-real, effective learning environments in the field of manufacturing systems is conceived. As a result competency-oriented Learning Factories meeting the industries' requirements can be implemented with the use of fewer input resources and an increased success in applied competencies in real situations.

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1. Introduction

Today's market challenges, such as shorter product life cycles and a rising number of product variants, require companies to quickly adapt to an ever more rapidly changing economic, social, and technological framework, in order to not lag behind global competitors [1]. Developing employees‘ competencies is a crucial prerequisite for a competitive, future-oriented production since it enables fast problem solving and continuous improvement in the whole production process [2]. Here, the concept of the Learning Factory offers a well suited approach to meet the industries' requirements: The continuous improvement philosophy is facilitated by individual actions and participants' active involvement as a genuine part of the overall learning concept [3]. To fully exploit the benefits Learning Factories offer, a competency-oriented, scientific-founded approach for the systematic development and configuration of these learning environments is necessary.

2. Learning Factories for competency development

Learning Factories pursue an action-oriented approach with participants acquiring competencies through structured self-learning processes in a production-technological learning environment. Learning Factories thereby integrate different teaching methods with the objective of moving the teaching-learning processes closer to real industrial problems.

In order to solve such problems, specific competencies are needed. 'Competencies are in general dispositions to act independently' [4]. In view of the dynamics of the market it is important to understand competency development in production as a crucial enabler for continuous improvement and staying competitive.

In recent years, quite a number of Learning Factories have been established worldwide which can be differentiated into Learning Factories for education, industry, and research [5]. To understand how these existing Learning Factories are configured a further assessment of their features is necessary. For a classification of Learning Factories regarding their potential on

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changeability, reference is made to the study of Wagner et al. [6]. Herein, the changeability of Learning Factories has been identified as an important design requirement in order to address a large variety of potential problems. More features of Learning Factories are covered in the survey conducted within the European Initiative on Learning Factories. This survey has addressed ten universities, all being members of the initiative, with the aim on creating a typology of existing Learning Factories (see Fig. 1).

characteristic	features					
operating organization	industry	consulting	university	technical college	professional school	
type of use	education / training	research	further industrial use			
industrial target groups	operational staff	engineer	manager			
academic target groups	students	research staff / post graduated				
other target groups	lean experts / lean specialist	other consultants				
selected industries	mechanical and plant industry	automotive industry	chemical industry	electrical industry	insurance, banks, etc.	
product	real product	arteficial (didactic) product				
production process	machining	assembly	logistics	IT	indirect	productio n
module content	process impr.	diagnosis	system design	quality control		
	quality	material flow	techn. opt.	lean transfer		
integrated departments	production	distribu- tion	pur- chasing	ideas mgmt.	design / develop- ment	prod. planning / control
integrated teaching methods	presentation	demon- stration	tutorial	web-based training	simulation game	
	discussion	case study	role play	experimen- tal game	learning cells	

Fig. 1: Learning Factory Typology

The typology maps a variety of features that combine to footprints of particular Learning Factories. The features highlighted red in Fig. 1 can be seen as the characteristic design features of today's Learning Factories as they are used, targeted, and integrated by all of the Learning Factories that have participated in the survey. However, identifying these characteristic features is not sufficient for developing new Learning Factories in a way that enables their full potential.

3. Current problems of Learning Factory design

Compared to traditional teaching, Learning Factories have achieved greater application-performance as well as higher degree of action-substantiating knowledge [7,8]. In terms of enhancing the success in competency development four problems of existing Learning Factories need to be dealt with:

First, existing Learning Factories were usually designed by technical experts of the simulated environment. For this reason, the resulting settings are strongly focused on the authentic mapping of real factory sceneries, without deriving the applied didactic concepts with a scientific approach to efficiency and effectiveness aspects regarding competency development [9]. Due to missing empirical evidence no statements on the strengths and weaknesses of different teaching-learning arrangements can be made. Accordingly, the integration of educationalists in the development of further Learning Factories is to be aimed in order to analyze, evaluate, validate, and redesign different Learning Factory arrangements [10].

Second, the development of Learning Factories is usually not based on any structured approach. The intuitive, experience based design of Learning Factories leads again and again to new pilot situations with correspondingly large pioneering efforts, and high uncertainty – at least initially, the result is a predictable low efficiency of the factory design process [9].

Third, regarding the planning of the Learning Factory hardly a competency-based approach is identified. Here, the media, didactical and technical design of Learning Factories has to be focused on an effective development of intended competencies [11]. Today considerable parts of intuitively designed training modules do not always contribute to the self-organized (participants') ability to act.

Last, the transfer of problem-solving procedures and waste elimination from Learning Factories to the real factory is often hampered by an inadequate allocation of staff to certain training modules, due to an often missing target orientation of training management [8].

4. The Learning Factory Curriculum Guide

Learning Factories should not only represent specific issues or problems in manufacturing engineering, but always aim at the development of the participants' ability to act self-organized in complex production environments [12]. So in the long term it is not enough to merely demonstrate state-of-the-art manufacturing environments – each Learning Factory must be based on a didactic-technological approach, which supports the development of participants' self-organized acting. The theoretically conceptualized approach of this paper will be referred to as Learning Factory Curriculum Guide (LFC-Guide, see Fig. 2). The LFC-Guide offers a systematic approach to design action-oriented, competency-based Learning Factories, which will be explained in the following sections. Additionally, the inclusion of didactic findings as well as a new target orientation of training management is provided.

The basic idea of the LFC-Guide is to provide a Learning Factory design which suits the development of required competencies for a certain target group of trainees. Thus, intended competencies represent a key component in the LFC-Guide (see Figure 2). They are the result of a systematic analysis of organizational and personnel conditions (i.e. purpose, production type, and target group).

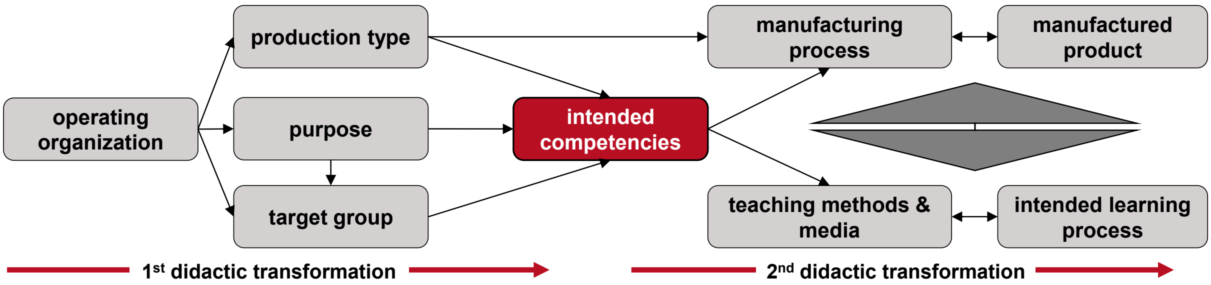

Fig. 2: Learning Factory Curriculum Guide

On basis of those competencies, both, the educational level ('teaching methods & media' and 'intended learning process') as well as the technological infrastructure ('manufacturing process' and 'manufactured product') of the Learning Factory are derived. In order to complete the Learning Factory design the educational level and the technological infrastructure must be aligned. In summary, the LFC-Guide follows two crucial steps of creating competency-oriented learning systems.

First, relevant subject matters with respect to the exemplary, the present and the future importance have to be determined [13]. And more essential, specific competencies defined as learning objectives must be conducted [12]. In the following the focus-setting as well as the content selection of most relevant aspects together with the identification of intended competencies is referred to as 1st didactic transformation [14].

Second, regarding specific conditions (like technology, participation, and regional specificity), the design of learning systems and suited learning situations in order to develop the intended competencies effectively is implemented. The configuration of a suited Learning Factory by planning instruction, interaction, and media will be referred to as 2nd didactic transformation [14,15].

4.1. The first didactic transformation

The LFC-Guide enables the focused competency development and facilitates the initial target formation in terms of a complete curriculum: The realization of those learning objectives – verbalized as intended competencies – must be anticipated, concretized and verified in the first didactic transformation [12]. Learning Factories have been individually designed by different organizations, e.g. producing companies, universities, vocational schools or consultant firms. Each of those operators has fundamentally different requirements for its individual Learning Factory.

The Learning Factory's type of production is directly dependent on the operating organization's targeted industry. Hereby, the complete range from one-off (e.g. large machine tools production) to high volume (e.g. automotive production) or continuous production (e.g. production of emulsion paint) can be covered. Likewise dependent from the operating organization is the Learning Factory's purpose. Identified manifestations are professional training, education, and research in production-related topics. In the individual case a detailed target specification is obligatory. The Learning Factory's target group is contingent on the operating organization as well as its purpose. Potential target groups may be students of bachelor and master study programs, consultants as well as professionals and managers of various hierarchy levels. Taking explicitly into account the Learning Factory's production type, purpose, and target group in the design process is decisive for exploiting its full potential.

Goal of the first didactic transformation is the formulation of intended competencies. Those competencies can be differentiated into four highly interdependent categories: Specialist and methodological competencies, personal competencies, activity- and application-oriented competencies and social-communicative competencies [16]. It is assumed that all four competency categories can be supported in Learning Factories. However, the Learning Factory focus lies in particular on specialist and methodological competencies [9].

The Learning Factory's intended competencies are derived from the three factors listed above, namely 'type of production', 'purpose', and 'target group'. Assigning specific actions and necessary knowledge to these identified competencies is an important step towards the development of teaching modules. Fig. 3 exemplarily shows such an assignment which can be referred to as 'competency transformation'.

Compe-tency	Sub-competency		Correspon-ding action	Knowledge base
Participant's ability to perform a waste analysis	1.1	Participant's ability to decide whether the waste analysis is useful in a specific situation	Decision on application of waste analysis	Knowledge about purpose and range of performing waste analysis; Understanding that a waste analysis is the starting point for process optimization
	1.2	Participants ability to identify waste	Recognition of waste in the analyzed area	Definition of waste and the concept of value; Knowledge about the process of waste analysis; Waste reduces the value and contradicts customer requirements; Waste is only identified with on-site visits
	1.3	...	...	... ...

Fig. 3: Competency Transformation

In this manner, the necessary knowledge base can be defined and unnecessary knowledge-elements can be excluded from training modules. Here, the knowledge base consists of technical, process, and conceptual knowledge, which can be action-substantiating knowledge or an action-overarching knowledge base [16]. The competency transformation establishes the basis for the subsequent second didactic transformation.

4.2. The second didactic transformation

In the second didactic transformation didactical and methodical reflections have to complement the technological infrastructure of particular Learning Factories. Based on the intended competencies suited teaching methods and specific learning processes have to be anticipated for methodic and medial modeling of the learning environment. In the following the key elements of the second didactic transformation are described in detail before their integration into the LFC-Guide will be discussed.

The challenge is to identify the teaching methods, which help developing intended competencies best. This is supported by a classification of methods according to their strengths and weaknesses [17]. Fig. 4 shows the classification of teaching methods in use within the research group. It covers teaching methods like presentation, discussion, case study, demonstration, role play, simulation, etc. following [10,17,18] and thereby creates a morphology of teaching methods.

Cluster	Criteria	Characteristic			
involved persons	degree of instructor-receiver involvement	emphasis on instructor	instructor-receiver involvement	emphasis on receiver	
involved persons	role of the instructor	lecturer	tutor	coach	mentor
learning environment	reality relationship of learning environment	traditional classroom	simulation environment	simulated real prod.	real factory
learning environment	work relationship of learning	work immanent	work bound	work related	
learning environment	spatial relationship of learning environment and workplace	separated	close to workplace	integrated	
learning environment	impact regarding the risk of production	low risk	medium risk	high risk	
process	type of learning process	external controlled	self-controlled		
process	transferability	low	medium	high	
process	subject matter in given time	low	medium	high	
resources	time flexibility for performing the teaching methods	low	medium	high	
resources	time effort for preparation and planning	low	medium	high	
resources	material resources	low	medium	high	
resources	spatial resources	low	medium	high	
resources	staff resources	low	medium	high	
resources	costs per participant	low	medium	high	
resources	requirements on instructor	low	medium	high	
resources	scalability of teaching method	low	medium	high	
resources	repeatability of teaching method	low	medium	high	

Fig. 4: Morphology of Teaching Methods, ‘Lecture’ exemplarily illustrated

When introducing new knowledge to participants of a Learning Factory module, a teaching method setup can be structured in two different ways. One way is by starting off with the theory and then showing problems to the participants, which they can approach with the previously learned. Hence, as an analogy to lean principles this way is dubbed ‘Theory Push’. Another way consists of a presentation of the problem to the participants before they know the theory, e.g. methods, on how to address it. With this – dubbed ‘Problem Pull’ – approach the participants are eager to learn how to solve the presented (ideally real life) problem and therefore ‘pull’ for the theory needed [3]. Fig. 5 shows the two teaching concepts described above as a course of events during a defined curriculum.

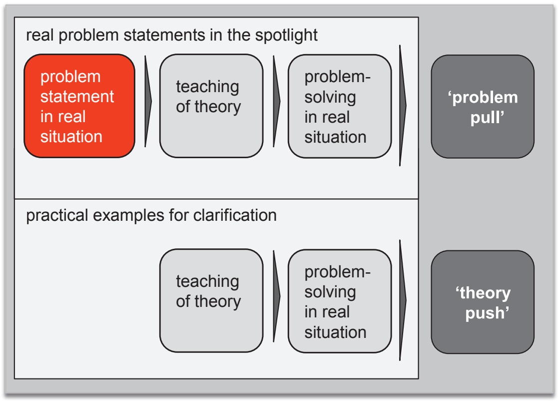

Fig. 5: Problem Pull vs. Theory Push [19]

To further describe the second didactic transformation applied in the LFC-Guide, the intended learning processes need to be specified. Here, the intended learning processes can be categorized into formal and informal learning processes, which are in opposition, but also complement each other in the Learning Factory concept [20]. Here, informal learning is action-oriented and usually includes problem-solving in an authentic environment. Even though the setting of the Learning Factory itself has more of a formal character, informal learning processes are observed during the hands-on exercises. In the Learning Factory context, the formal learning processes usually contribute a science-oriented, objective part of the program, e.g. during the presentation and explanation of necessary professional and conceptual knowledge. Formal and informal learning complement one another as the utilized teaching methods not only impart knowledge but develop participants’ competencies [21]. In order to create authentic project situations in various specific learning settings, the intended learning processes are based on the model of complete action, which describes a closed loop of planning, executing, and evaluating [22].

Many established Learning Factories have selected their product and corresponding manufacturing processes prior to identifying the competencies they want to build up. In contrary, this paper states the need of utilizing the manufactured product and the manufacturing processes as well as teaching methods and media respectively as a support to develop the intended competencies. As shown in Fig. 2, these elements exist in a complex, mutual dependency. After having described the educational level of the Learning Factory, the following paragraph explains the technological infrastructure.

The designated production type has a significant influence on the manufacturing processes to be selected, since those processes strongly affect the authenticity of the created learning environment. The process engineering industry, for example, has different requirements on the manufacturing processes in the Learning Factory than the serial production industry. Thus, in this case the manufacturing processes should preferably map continuous production over single dispatch item production.

Additionally the manufacturing processes together with the product should correspond with the teaching methods used in the Learning Factory in conveying the intended competencies. Therefore, as described above, these competencies need to be identified prior to establishing the manufacturing processes and the product in the Learning Factory.

Altogether the adjusted design of the technological infrastructure and the educational level represent the second didactic transformation in the LFC-Guide.

5. Research aim and methodology

Research aim is the validation of the LFC-Guide. To support its underlying assumptions, a systematic multi-level study with 20 Learning Factories is conducted. The study consists of a triangulation of expert interviews and on-site process observations and reveals relationships within specific fundamental design parameters, e.g. layout, product, and learning targets. This allows linkage to suitable Learning Factory configurations.

The semi-structured interviews conducted with personnel of existing Learning Factories in Europe form the first part of the study. The study group consists of Learning Factories operated by universities, companies, dedicated consulting firms, and vocational schools. To draw qualitative conclusions about the technical-didactic approach, an interview questionnaire geared to the structure of the LFC-Guide is created.

In the second part of the study, a qualitative empirical survey is conducted, which consists of on-site observations of training courses with industry personnel at selected learning factories by research staff from didactics and production engineering. The investigation of the complex competency development (both specific and multidisciplinary) is accomplished with detailed case-by-case analyses. Furthermore the influence of individual dispositions, such as general and specific professional interests, epistemological beliefs, motivation to learn and perform, and the attitude to study, on the individual learning outcome is examined. Hereby, the specific observation focus is on the complementation of formal and informal learning processes.

6. Results

Studies involving European Learning Factories suggest a positive impact on the design process as well as the designed learning system using the structure described and the links suspected in the presented LFC-Guide.

In the interviews conducted, the LFC-Guide is considered consistent. The underlying elements of the guide are evaluated by the surveyed experts as a complete, self-contained coverage of all factors influencing the Learning Factory planning and implementation. An industry interviewee identifies the advantage of the LFC-Guide in the fact that "(…) the guide explains from a didactic point of view, what elements we need to consider and in which order to plan our Learning Factory." Overall, from the evaluation of expert interviews and on-site participative observations three main results for designing new Learning Factories along the LFC-Guide can be accentuated:

- Competency-oriented design of learning targets
- Consideration of a didactic orientation
- Integration of heterogeneous target groups in the Learning Factory modules

Regarding the competency orientation, all interviewees explicitly point out the building of capacity to act in complex real-world situations as the primary goal of a Learning Factory. This mentions implicitly the importance of the development of competencies to solve complex problems and tasks in the field of manufacturing engineering. Such a disposition for real-life situations can only be achieved with a competency-oriented curriculum. Therefore, learning targets of Learning Factories are aligned accordingly, i.e. the assigned actions as well as the respective corresponding knowledge elements for intended competencies have to be enlisted.

The participatory observations in training programs with industry employees demonstrate the importance of considering a didactic orientation in the Learning Factory. In particular by integrating reflection and feedback elements in training modules, it is possible to complete the learning process and thus improve learning outcomes. The ratio between self and external control of learning processes has to interact with the surrounding teaching-learning arrangement. Neither classroom instruction only nor a fully self-directed learning process promises best results. The didactic-methodological configuration of training programs should always be designed – in consideration of efficiency criteria – using a combination of teaching methods in order to control the self-learning processes.

In most of the surveyed Learning Factories, including the Process Learning Factory CiP, different target groups are so far predominantly trained in homogeneous groups. In the interviews experts agree, however, that the Learning Factory treatment should particularly prepare the cooperation of employees in real workplace situations. Therefore, Learning Factory curriculum modules should consider the design of special programs that are aimed at heterogeneous target groups as a requirement. An interview partner from industry confirms this claim arising from his own practical application: “In our Learning Factory we seek to provide trainings with the entire group. This way we can address the future cooperation within this group directly.”

Overall, the results support the structure of the LFC-Guide as well as its relationships for configuring a systematic, didactic well-founded and competency-oriented Learning Factory.

7. Conclusion

The study described in chapter 5 will be continued and further assesses the LFC-Guide and the associated system ‘Learning Factory’ in additional quantitative studies. These will be focused on companies that do not have a Learning Factory, yet. Furthermore, the study is planned to be extended to implement the LFC-Guide in setting up a new Learning Factory in an efficient and structured manner.

The introduced LFC-Guide offers a new approach for the systematic development of effective and more efficient Learning Factories. It addresses the problems of early adopted Learning Factories, like the missing target orientation or inadequate integration of didactic findings. As a result competency-oriented Learning Factories meeting the industries’ requirements can be implemented with the use of fewer input resources and an increased success in applied competencies in real situations.

The results drawn off the studies are promising, though they are limited to experimental studies within the Learning Factories, blanking out transfer abilities of participants. However, since Learning Factories are no end in itself, positive outcomes for participants and companies are necessary. Future research should include the processes before and after the Learning Factory – configuring and setting it up beforehand as well as the participants applying the taught methods in practice. This way, a continuous improvement of the Learning Factory is enabled. Thus, the participation in a Learning Factory needs to be considered a real treatment.

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