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Hybrid learning factories for lean education: Approach and morphology for competency-oriented design of suitable virtual reality learning environments

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Abstract. In recent years, learning factories have proven to be an effective instrument for developing competencies, especially in lean production and digitization. The concept of learning factories has been enriched in the recent past by elements and training units in virtual reality (VR). This enrichment allows an expansion of the mapping abilities of different training environments and value streams in the context of lean education. Nevertheless, learning factory developers are faced with the challenge of selecting suitable scenarios in terms of content and scope. An approach for the competency-oriented and structured design of such scenarios will be presented in this publication and illustrated by means of an application example of the research project PortaL (Virtual action tasks for personalized, adaptive learning).

Keywords: Virtual Reality, Learning Factory, Learning Environment, Lean Education

1 Introduction

The achievement of strategic goal, innovative capabilities and finally profitability depend strongly on the ability to build up the relevant competencies and to use and further develop the existing competencies of employees efficiently. Companies and other institutions are measured by how well they are able to leverage their knowledge to create value [1]. Learning factories have proven to be an effective tool to develop competencies. By using VR, the mapping capability of learning factories can be extended [2]. If a learning factory applies both physical and virtual elements, it is called hybrid. The goal of this publication is to present a procedure for the development of virtual training scenarios in hybrid learning factories.

2 Virtual reality and learning factories

Learning factories provide a reality-conform production environment for learning [3]. Virtual learning factories are basically used for training in the same areas as traditional

physical learning factories. Mostly, the tasks of the trainings originate from the planning or simulation background [4]. Several learning factories address lean education topics. They can be seen as an extension of digital learning factories, as they provide visual software tools and infrastructures such as user interfaces to enable the visualization of digital models [5]. Virtual learning factories enrich physical learning experience by a higher degree of flexibility and expanded opportunities. Therefore, it is important that the virtual learning factory represents the real learning factory in all its relevant processes, activities and resources [5]. Using VR for the development of competencies in virtual learning factories thus offers several advantages. Due to adaptable virtual environments, the learning scenarios can be personalized specifically to the learner [6]. Additionally, acquired knowledge can be tested in the virtual environment without generating economic damage. To be able to design a constructive learning environment, the focus of competency development should be on the application of the learning content, not on the reproduction of knowledge. The learner should thus be given authentic tasks that correspond to the intended competencies. The prerequisite for competency development in a virtual environment is, on the one hand, the use of the interaction possibilities and, on the other hand, the link to a learning outcome [7]. Finally, it is important to develop and consolidate the necessary competencies with the help of transfer-based action tasks.

3 Methodology

The primary goal of the methodology is to develop virtual learning scenarios that are able to develop the intended competencies while being adaptive and individualizable. Thus, the advantages of VR technology can be implemented, and competency development can be individualized and personalized.

3.1 Development of the VR scenarios

The development process involves the inclusion of three steps, as shown simplified in Figure 1. The development of a scenario for a virtual learning factory is close to the development of a physical learning factory. Based on the design approach by Tisch for physical learning factories [8], the first step is to clarify the organizational requirements (step 1). This includes the organizational environment and targets as well as the target group. In the second step, the learning targets and intended competencies are deduced (step 2). Finally, the configuration or design of the learning scenario is developed based on the previous steps. This includes the design of the product and processes, which should also be based on didactic principles (step 3).

The first two steps are identical to the procedure for a physical learning factory scenario. In the first didactical transformation the intended competencies are derived from the organizational requirements or environment, the organizational targets and the target group. In the second didactical transformation the socio-technical infrastructure and didactical aspects are derived from the intended competencies [9]. This approach can

also be applied when a virtual learning factory scenario needs to be designed, but additional (e.g., maximum time in VR) or changed requirements (e.g., space for VR tracking) need to be observed.

Once the organizational requirements and learning targets have been defined (these two steps are not in focus of this paper), the concrete configuration (infrastructure and didactics) of the scenarios takes place within the third step, the design phase. A learning factory has two central characteristics that should be represented in the infrastructural and didactical aspects of the virtual scenarios: On the one hand, the high contextualization of the learning environment (i.e., a factory environment that is close to reality) and, on the other hand, the possibility of the learners' first practical experiences. However, the contextualization should not be too detailed, firstly because of the high complexity of the implementation in VR and secondly because of the risk of overtaxing the participants. The scenario should contain interaction possibilities which allow the user to perform the competency-relevant action tasks and it should facilitate the necessary thought processes for problem solving. The implemented actions should offer a combination of orientation, planning, execution and control. At the same time, the possibilities that VR offers for design should be used (e.g., novel ways of visualization or presentation of assistance) [10].

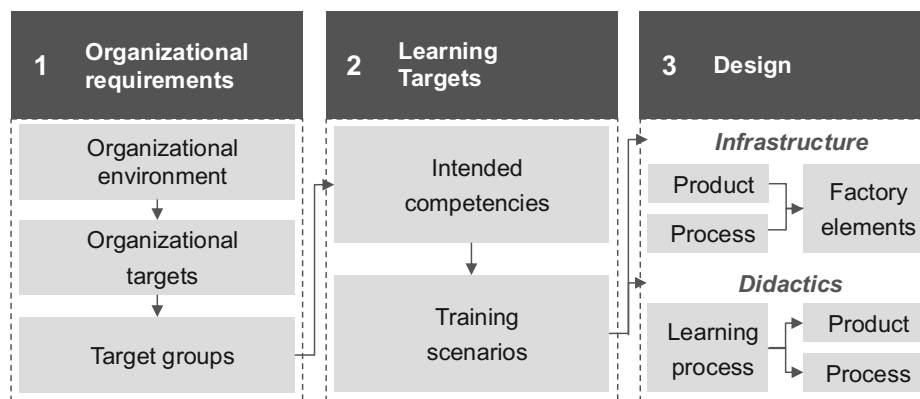


Fig. 1. Approach for competency-oriented design of suitable virtual learning environments [8].

In context of the design, reference is made to the design levels and the design dimensions by Tisch. The design levels are considered vertically at the macro (e.g., learning factory infrastructure), meso (e.g., teaching modules) and micro levels (e.g., specific learning-teaching-situations) [9]. The scenarios are set within a content-related and temporal framework. The individual activities of the scenarios are found on the micro level. Accordingly, it is particularly important to design the micro-level or the individual learning situations. In the context of planning a learning factory, there are five design dimensions that are based on factory-specific or learning-specific problem areas, such as the operator model, the mapped processes or the didactic reference [8]. In addition, a scenario design can follow three different product strategy approaches. A

design from product to process, from process to product or a parallel product and process design [8]. In order to exploit the potential of VR, a parallel product and process design can be chosen. Both the processes and the product should in principle be freely selectable. The choice of products for learning factories also offers two paths. Either industrial products already available on the market are chosen with the aim of completing the learning factory configuration or the development of customized products for fitting into the learning factory concept is aimed at. Mapping in virtual space offers the freedom to adapt processes and products without having physical dependencies [8].

Fig. 2. Proposed extension of the leaning factory morphology by Tisch [11] for virtual learning factory trainings (expressions chosen in the research project PortaL underlined)

	Aspect	Expressions			
V.1	Application time	Before physical training	During physical training	<u>After physical training</u>	
V.2	Duration	< 5 min	<u>5 - 30 min</u>	> 30 min	
V.3	Goal of usage	<u>Personalization</u>	Flexibility	Transfer	
V.4	Hardware connection	<u>Wireless</u>		Wired	
V.5	Output Devices	<u>HMD</u>	<u>Desktop</u>	Mobile Devices	
V.6	Type of use	Completely Virtual		<u>Hybrid</u>	
V.7	Development process	Internal	<u>External</u>	Cooperation	Use of available modules
V.8	Trainer role	<u>Coach</u>	Mentor	Lecturer	Moderator
V.9	Place of implementation	<u>On-Site</u>		Remote	
V.10	Simultaneous physical participants	<u>1</u>	<u>2-5</u>	6-10	>10
V.11	Simultaneous virtual participants	<u>1</u>	<u>2-5</u>	6-10	>10
V.12	Number of production environments	1	<u>2-3</u>	>3	
V.13	Number of processes presented	1	2-3	<u>≥3</u>	
V.14	Number of difficulty levels	1	<u>2</u>	≥3	
V.15	Introduction to the technology	<u>Presentation</u>	<u>Virtual tutorial room</u>	Individual briefing	

The potential of being able to change situations in VR through appropriate programming offers many further possibilities for individual adaptation and removes limitations. At the beginning, a selection should be made and can result in a set of difficulty levels from which a participant can choose. By selecting the appropriate difficulty levels, participants should not feel under- or overchallenged. Necessary time differences in the implementation can be put into perspective by the possibility of adaptation. At the same time, learning factory operators and developers are free to use this multitude

of degrees of freedom also in the context of the implementation method. This results in a table with a total of 15 fields of action. This table can be seen as an addition to the learning factory morphology introduced by Tisch [11].

These different expressions allow learning factory developers or learning factory operators to specifically address currently existing weaknesses of the physical learning factory concept. VR can allow remote learning with realistic scenarios as well as the adaptation of difficulty levels and scenarios offered.

4 Results

In the context of the research project PortaL, the approach presented in section 3 was tested with five potential learning environments. In the following, one of these learning environments will be briefly presented on the basis of the three steps *organizational requirements*, *learning targets* and *design* of the approach.

4.1 Organizational requirements

In the PortaL research project, the contents of the configuration scenarios are to be determined above all, whereby the organizational requirements as well as the learning targets were already available as given. The teaching-learning concept fits into the existing curriculum of the Process Learning Factory CiP at the PTW of the TU Darmstadt and aims in particular at employees of small and medium-sized German companies as a target group. The primary learning content is composed of lean manufacturing topics. In order to further specify the requirements with regard to VR, these were analyzed in a literature-guided manner in the research project and were evaluated in stakeholder interviews [12, 13]. For example, it is required that different learning types are taken into account. This can be done by offering a redundant information output, for example in visual and auditory form.

4.2 Learning targets

For the application example, the learning targets and intended competencies are organized around the topic of value stream analysis. The learning targets were derived from the already existing physical value stream analysis learning factory workshop, which serves as a basis and is to be enriched by a virtual learning unit as part of the research project. The focus is to provide a complementary virtual scenario for the application of the learned method in a scenario close to the participants own professional environment.

To illustrate the procedure, value stream mapping was chosen as an example application. The primary objective of the value stream analysis is to analyze the actual state of a production value stream. In addition to the recording of process and cycle times, this also includes the recording of process links, inventory types and quantities as well as wastage (e.g., employee waiting times, inventories, etc.) that occur within the value

stream. Other aspects, such as drawing the value stream map on the basis of the data obtained, can in principle also be represented in VR. In the context of the teaching-learning scenario presented, however, it was decided to leave this action task in the physical, real space, since a virtual whiteboard application would not offer any advantage over the physical variant with regard to the learning objective.

4.3 Design

With the specifications outlined in the two previous subsections in mind, the learning scenarios were designed. On the one hand, care was taken to ensure that all relevant action tasks could be mapped and, at the same time, that the maximum targeted duration of the virtual scenario does not exceed 30 minutes. The maximum duration can vary from participant to participant, but the selected value should be possible for the majority of participants without suffering from fatigue or other physiological reactions, such as motion sickness. Based on this restriction of a maximum learning time in VR, three to four virtual production processes should be designed. This amount was also chosen for the later defined scenarios. At the same time, all scenarios were conceptualized in such a way that at least three product variants can be represented in each scenario. Certain other strengths of VR (e.g., different types of visualizations, manipulation of time, etc.) can be considered and implemented later.

For the definition of the used products the development of customized products for fitting into the learning factory concept and a parallel product and process design were chosen. Therefore, on the basis of suitable literature on the topic of competency-oriented learning factories, five first production scenario approaches (for printed circuit boards, sheet metal profiles, design objects, toys and siccors) with a low level of complexity (4-5 production processes for each scenario) were developed and evaluated by experts in the next step. The team of experts consisted of scientific staff of the PTW, learning factory experts, experts from the field of didactics and a developer of VR environments. For the evaluation of the scenarios five criteria which should facilitate a competency-based scenario design were derived from the literature and the requirements of the research project. With the help of a pair comparison, a weighting of the individual criteria was achieved. The criteria and their respective weighting are the following:

- Added value compared to existing value stream (.27)
- Target group fit (.24)
- Low distraction (.20)
- Variant mappability (.20)
- Attractivity (.09)

The five potentially suitable scenarios were evaluated regarding the respective suitability of the scenarios among each other using the criteria named above. A utility analysis was used as an evaluation tool. The fulfilment of the criteria in the respective scenario was evaluated on a six-point scale from *not fulfilled (0)* to *completely fulfilled (5)*.

The outcome of this evaluation decided which two approaches would be further developed.

The evaluation of the five scenarios showed (normalized results in brackets) that a production of *printed circuit boards* (1.0) and a production of *sheet metal profiles* (.95) seem to be the most attractive and suitable for the intended purpose of a virtual learning factory workshop with the goal to develop competencies regarding value stream analysis. The other three production scenario options, *design objects* (.90), *toys* (.86), and *scissors* (.84), scored lower in the expert rating and were therefore not further detailed. After the scenarios to be used were determined, they were extensively examined for adaptability and personalization and the possibilities were incorporated in detail into the concepts.

Scenario in detail: Sheet metal profiles

The value stream consists of a total of 4 processes. In addition to a warehouse, the scenario consists of the production processes *cut to length*, *laser cutting*, *bending* and *testing*. Three product variants can be manufactured within the value stream. In addition to the execution of all competency-relevant action tasks (recording of relevant times, process links, stock types and waste), the value stream also allows, in particular, the observance of residence times in VR that are suitable from the project point of view. Despite covering all relevant content, the scenario is still kept lean enough to be explored completely within 15-30 minutes.

5 Discussion and Outlook

In the context of this publication, a procedure for the structured design of competence-oriented teaching-learning environments was presented alongside a morphology for the classification of virtual teaching-learning environments. Both elements emerged as a result of the research project PortaL and were already used there for the development of three teaching-learning scenarios. Although the principal suitability for the creation of teaching-learning scenarios could already be tested by the application for development as well as in smaller application tests with the virtual environments, a detailed evaluation is still pending. This is to take place in the near future to provide results on the suitability of the developed environments for competence development. With confirmation of suitability, the approach can provide a valuable contribution for developers to develop competency-based teaching-learning environments and to classify existing or new environments. Nevertheless, the proposed morphology can be used for the design of future learning scenarios in learning factories.

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