11th Conference on Learning Factories, CLF2021

# Approach for conceptualization and implementation of virtual reality in learning factories

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**Abstract**

Learning factories are already in their physical design a complex and expensive tool for vocational training. However, despite the high-quality learning factory concepts available today, the complexity of the industrial production environment makes the transfer of intended competencies into the operational application situation a challenging task. With Virtual Reality (VR), this challenge can be met by adapting the learning environment and personalizing the learning scenario to the respective participants. Though, the adaption of the learning environment to the expected participants brings new challenges. In addition to the necessity of a clear definition of target groups and intended competencies, which is also present in the physical concept, there are further challenges for VR, e.g. the selection of design elements in the virtual environment or the best possible integration of virtual learning scenarios in hybrid learning modules. That can be met with a reasonable conception and implementation process: in the research project PortaL, a multi-stage procedure with nine sections in three phases was developed that assists the structured conceptualization and implementation of virtual learning scenarios and offers a better experience for the participants. The presented approach guides its users through the definition of objectives and requirements as well as the actual concept and evaluation phases. These aspects are covered among others and are presented in this publication.


Peer Review statement: Peer-review under responsibility of the scientific committee of the 11th Conference on Learning Factories 2021.

*Keywords:* Virtual Reality; Learning Factory; Virtual Training; Learning Factory Design; Competency Development

## 1. Introduction

The development of competencies as a key competitive factor is becoming increasingly important. Therefore, learning factories are an effective tool for competency development, since they allow professionals and young engineers to learn in realistic production environments [1]. Virtual Reality (VR) offers many opportunities in the field of education [2, 3] and expands the possibilities and areas of application in learning factories [4]. Virtual learning scenarios are implemented only by a few learning factories, although the concept of virtual learning factories was introduced years ago [5]. Additionally there is no approach known, which helps to easily and structurally implement virtual learning scenarios in learning factory contexts. The approach presented in this publication aims to close this gap by offering a structured and simple approach for the conceptualization of VR learning scenarios in learning factories and makes it simpler for learning factory developers to incorporate virtual elements in their workshop concept.

This paper's main focus is to present an approach for the conceptualization and implementation of VR in learning factories. Therefore, the paper is divided into five sections: In the first section, the foundations of learning factories and VR are explained. After reviewing the basics of learning factories and VR in the field of education in the second section, the underlying methodologies for the approach development are presented in the third

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section. These contain the competency-oriented approach by Tisch et al. [6] and a didactic centric approach by Kerres [7]. The fourth section describes the approach itself, which contains nine stages in four concept phases. The approach and the current limitations are discussed in the fifth section, followed by a summary and outlook in the sixth section. Learning factory operators who consider implementing VR in their learning factory can use the approach of this paper to implement VR in their existing concepts or generate new ones.

## 2. Learning factories and VR

Learning factories enable the development of production-related competencies in a realistic environment apart from the actual workplace. Participants can perform tasks within a real value stream for a physical product [1, 8]. Nevertheless, learning factories are associated with several limitations, which may relate to didactical aspects (e.g., limited mapping abilities [8]) and others, in addition to more organizational and economic aspects. To address these limitations, virtual learning factories were developed during the last years [5].

VR can be understood as an interactive computer-based simulation of reality [9]. It has seen rapid progress over the past decade, particularly in terms of device performance [10]. Looking at the gradient between physical environment and VR (see Fig. 1 below), a pure virtual environment, compared to mixed or augmented reality formats, is characterized by the fact that the participant is completely immersed in the virtual world and a sensory link to the real world is largely excluded. Immersion describes the state in which the illusion moves into the background so that the virtual world is perceived as real [11].

In virtual learning factories takes place in a virtual environment [12]. This also reflects a general trend according to which VR learning environments are increasingly used in vocational education and training as an additional education tool [13]. A hybrid learning factory ceoncept combines the advantages of the physical and the virtual environment [1]. These two concepts open various possibilities for extending the existing operator model. Although the concept of virtual learning factories is no longer a new one, the implementation of outright virtual and hybrid learning factories has still not gained a broad distribution among learning factories.

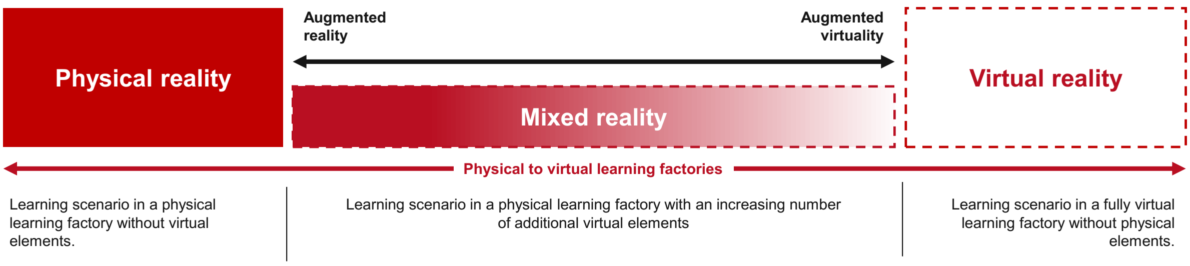


Fig. 1. Gradient between reality, mixed reality and virtual reality in the context of learning factories based on [4, 14].

In recent years new learning technologies are applied more frequently in vocational education and training.. Virtual settings in the form of VR open up new learning spaces. With head-mounted display the learners have the feeling of being able to move physically in it [11]. Virtual worlds reveal exploration, training and construction worlds for learners [9]:

- In *exploration worlds*, learners explore various subject areas that were previously inaccessible. The virtual environment provides learners with flexible access.
- *Training worlds* aim to acquire action-related skills and abilities.
- In *construction worlds*, learners explore the virtual world self-directed and can construct own objects in VR and also own virtual worlds. The learners interact self-controlled with the virtual world [9].

VR as a supplemental or substitutional element for educational contexts holds various potentials, especially for learning factories: VR brings *flexibility* to time and place [2]. Processes can be shown in slow or fast motion. It is possible to manipulate time and objects to show complete processes in a workshop that would not be able in reality due to their duration. Depending on the training participants' wishes, a high number of value chains with different products can be presented. It is possible to *address different types of learners* simultaneously [15]. The level of difficulty of the exercises can be varied according to the needs of the participants and the didactic concept can be supplemented by *new types of reflection*. This allows a new level of *adaptivity and personalization* of learning factory formats. Even though there are numerous potentials of VR for further education, new technology is also associated with challenges. In particular, the literature lacks detailed explanations of *media-didactic concepts* regarding VR [e.g. in 7]. Similarly, the requirements placed on educational staff are changing when digital media is used in the teaching and learning process. The use of VR contributes to the fact that the transfer of knowledge by the teacher is no longer in the foreground. The role of the teacher has changed. The teacher acts primarily as a coach and supports the learning process [13, 16]. Although there are already approaches on how existing learning factories can be developed further [17, 18], there is a *lack of general concepts* on how the implementation of VR in learning factories can be conducted systematically. This gap is addressed by an approach developed in the PortaL research project.

In the research project "Virtual action tasks for personalized adaptive learning" (PortaL) a personalized training scenario is developed in VR. The focus is on adapting and personalizing the learning process in VR. After a training course in the physical learning factory, the participants conduct a personalized exercise in the virtual learning environment. The approach was developed within the research project and will initially be implemented in the Process Learning Factory "Center for industrial Productivity" (CiP) at Technical University of Darmstadt using the example of an existing training course.

## 3. Methodology

The foundation for the proposed approach is the systematic approach on developing action-oriented learning factories by Tisch et al. [6]. To design learning factories, three conceptual design levels and two didactical transformations must be considered, which are used in virtual learning factories while considering new requirements. The following three design levels are relevant for the design of learning factories [6]:

- The *macro-level* includes the infrastructure of the virtual and hybrid learning factory and the curriculum.
- The *meso-level* includes learning modules.
- The *micro-level* includes teaching-learning scenarios, which are represented virtually or physically.

For the didactical transformations, the following definitions can be made [19]:

- The *first didactical transformation* derives the intended competencies from the organizational environment (e.g. production type), the organizational targets (e.g. purpose) and the target group. The inclusion of virtual elements does not change the first didactic transformation.
- The *second didactical transformation* derives the socio-technical infrastructure (e.g. manufacturing process, manufactured product) and didactical aspects (e.g. teaching methods & media, learning process) from the intended competencies. In this transformation step it is also relevant to align both didactical as well as technological aspects. In hybrid learnining factories, additional virtual design elements are considered for the second didactic transformation.

In addition to the adapted design approach of learning factories according to Tisch et al. [6], there is a need to consider the media-didactic discourse when designing a hybrid workshop concept. Here, the research project PortaL refers to the criteria for the conception of media-supported teaching-learning offers, according to Kerres [7]. The guideline concept takes up aspects such as the determination of the target group, the selection of the method, the definition of the learning content, selection of the medium, and a final evaluation [cf. 7]. It should be emphasized here, however, that in the following chapters only a broad understanding of the criteria according to Kerres was used, and a deeper examination of the media-didactic conception of the hybrid workshop concept is needed.

Based on the learning factory design concept and the media didactic guidelines, the approach was adapted to integrate virtual elements as best as possible in existing or newly created learning factory workshop formats. The approach shall meet the named criteria below:

- Simple and structured procedure leading the user through the conzeptualization process
- Universal applicability for use in hybrid and purely virtual application contexts
- Competency-orientation
- Media-didactic-orientation
- User-orientation throughout the entire process

## 4. Results

For the research project PortaL an approach to conceptualize and implement VR for the purpose of a supplemental training scenario in an existing learning factory training was developed. As shown in section 3, the approach was developed in the context of the competency-oriented design approach of Tisch et al. [6] and considering media didactic aspects according to Kerres [7]. These two concepts require in particular the definitions generated in the steps on initial situation, requirements as well as learning scenarios and evaluation. The developed approach consists therefore of four phases, divided in several steps shown in Fig. 2 and 3 below.

### *4.1. Phase 1: Initial situation, objectives & requirements*

For further development, especially if software partners are involved, the chosen *development method* of the virtual environment is crucial. In the area of software development, an agile approach is widely chosen today. As described by Riemann et al. [20], another advantage is to obtain user feedback as early as possible and to design the learning environment in a user-oriented way. The development method should be defined as early as possible, since it defines the project structure and design processes.

To create a solid foundation for the conceptualization and implementation, the *objective* and *initial situation* (in which the development of the VR scenario takes place) should be analyzed. To meet the requirements for competency orientation intended competencies, the relevant target groups and the didactical concept are derived. The exact value a VR scenario can offer for an already existing workshop concept needs to be elaborated. This can partially be done by considering the challenges of the existing didactical concept and deriving VR potentials. A list with challenges and chances of VR in the vocational education can be found in Riemann et al. [21].

Derived from the first steps but also from other sources like stakeholder interviews or literature review, a set of *requirements* needs to be created which can serve as a starting point for a specification sheet. Especially in agile development modes, a prioritization for the implementation of the relevant requirements is needed. In the research project PortaL, the mining for requirements was done by a structured literature analysis as well as stakeholder interviews. The derived requirements were then categorized into must-be, performance and attractive and prioritized by stakeholders using the Kano model. The chosen method can be found in detail in Riemann et al. and Kreß et al. [20, 22].

### *4.2. Phase 2: Software*

The step of *software development* is not in this paper's focus and therefore visualized only dotted in Fig. 2. However, it can be worthwhile to acquire external experts and partners for the software development, since a successful implementation of VR environments requires a certain degree of experience. In addition, due to the number of software iterations required, to achieve the necessary user orientation, software development should be started as early as possible.

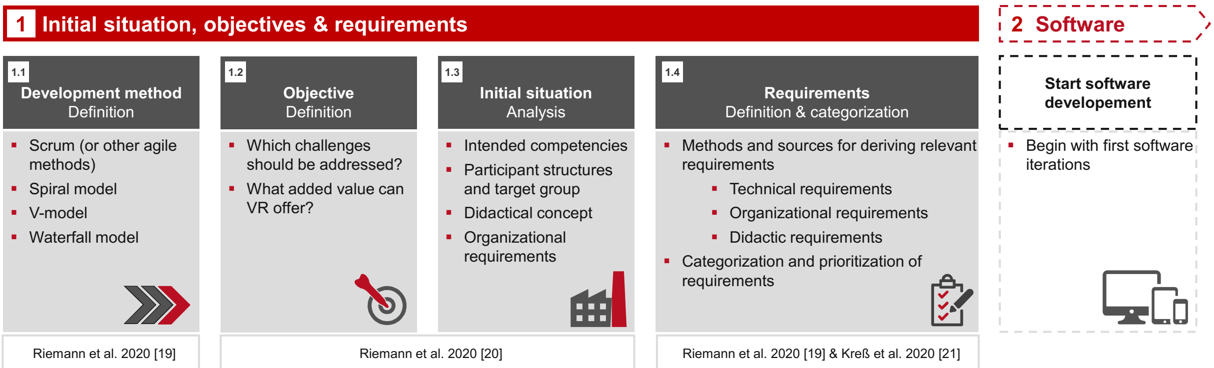


Fig. 2. Approach for conceptualization and implementation of VR in learning factories: phases 1 and 2.

### *4.3. Phase 3: Concept and design*

Subsequently to the technical, organizational and didactical requirements, *learning scenarios* must be defined and selected. For hybrid learning factories, this includes the content definition as well as the distinction which sub-competencies and corresponding action tasks should be mapped in VR and which in physical space. Not all action tasks need to be mapped in VR since it might be more intuitive to represent them in the physical space. For example, for the learning content of value stream mapping considered in the project, the data collection is done in the virtual space, but the creation of the value stream map itself is done on whiteboards in the physical space since the mapping of it in VR would be cumbersome.

Starting from the scenario definition, it is possible to define explicit *design elements* in the next step. These design elements can be understood as explicit expressions of a single detail or aspects of the virtual world. To design the VR environment in a user-oriented way, it might be helpful to create different options for representing a single action task or design element in VR. For all design elements, design principles in the context of VR must be considered. To structure the generation process of design elements, a three-pillar model was developed to determine suitable design elements depending on their interaction level. A detailed description can be found in Riemann et al. [23].

The *hardware* selection is on the one hand substantial for a single implementation project but should on the other hand also be a strategic selection (e.g. in the context of planned successive VR expansion of the workshop portfolio). It is difficult to locate it in the concept, since the decision can in principle only be made as soon as the requirements for the virtual environment and design elements have been defined. Nevertheless, software development is currently only possible in a meaningful way once the hardware has been defined. In anticipation of possible future standards as well as the importance of the strategic selection of hardware  it was decided to implement this in the concept at the end of phase 3.

*4.4. Phase 4: Implementation and evaluation*

In the last phase, the *implementation* of the VR scenario in an existing or new training context. To create a seamless integration of the VR scenario the success factors for VR should be taken into account. In this phase, several aspects have to be be considered, e.g. learning group sizes, available hardware sets, length of VR sessions, alternatives for individuals who respond with physiological reactions (e.g. motion sickness).

The last phase of the approach captures the *evaluation and further development* of the learning scenario. For the user orientation, it is crucial to develop the scenario further and implement feedback of stakeholders continiously. This can also mean that findings and feedback can be used for existing or completely new training scenarios.

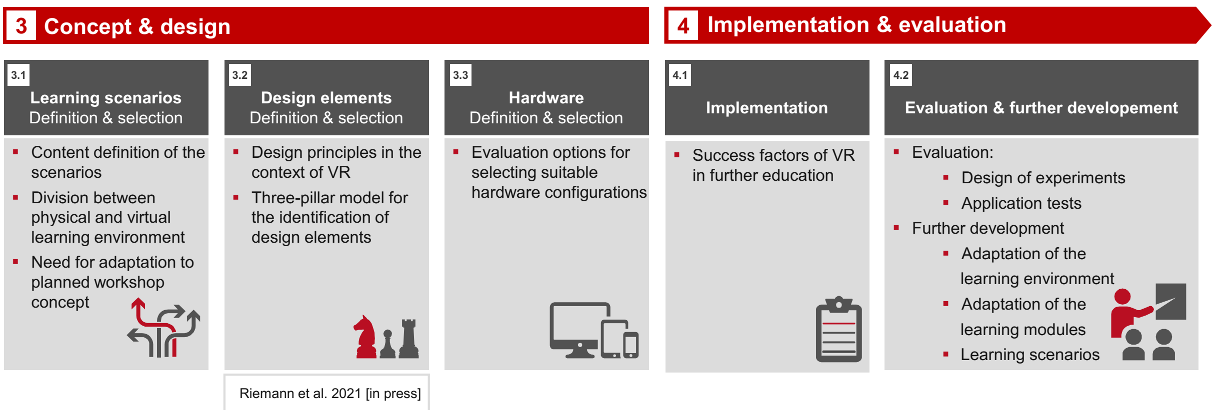


Fig. 3. Approach for conceptualization and implementation of VR in learning factories: phases 3 and 4.

## 5. Conclusion

*5.1. Discussion*

The outlined approach can be seen as suitable for the conceptualization and implementation of VR learning factory training scenarios. It was shown that the approach can help learning factory developers to implement VR in hybrid learning factory contexts successfully. During the research project in which the approach was developed, it was simultaneously used to obtain a learning scenario for value stream analysis training. Initial user tests confirmed that this resulted in a learning environment that is easy and intuitive to use. The learning environment maps all relevant aspects that allow the execution of the relevant action tasks.

Nevertheless, the approch still lacks qualified evidence to confirm its suitability. Further research must generate a solid data base to evaluate this approach in context of the named criteria in the third section of this publication.

### 5.2. Summary and outlook

In this publication an approach for the conceptualization and implementation of virtual learning environments was shown, which can be used by learning factory developers and operators to introduce VR in their concpets. After introducing the foundations for the approach, the single phases and stages of the approach were explained. Further research needs to clarify whether the learning scenario resulting from the approach is suitable for developing competencies and for the use in learning factories. The proposed approach needs to be evaluated on the basis of the critera named in section 3 of this publication among others. The evaluation concept as well as the results of the evaluation will be published in the future. Additionally to the publication of the evaluation results further publications will follow to addresss the aspects of the didactic concept, the scenario and hardware definition.

## Acknowledgements

The authors would like to thank the Bundesministerium für Forschung und Bildung (Federal Ministry of Education and Research, BMBF) and the Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center, DLR) for financial and administrative support during the project “Virtual Action Tasks for Personalized Adaptive Learning” (01PV18001A).

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