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Evaluation of an immersive virtual learning environment for operator training in mechanical and plant engineering using video analysis

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Abstract

A structural evaluation is imperative for developing an effective virtual learning environment. Understanding the extent to which content that has been learned virtually can be applied practically holds particular importance. A group of persons from the technical field of mechanical and plant engineering ($N = 13$) participated in a virtual operator training for a case application of additive manufacturing. To evaluate the virtual learning environment the participants answered quantitative questionnaires and were asked to apply what they had learned virtually to the real machine. Both the virtual training and testing phase on the real machine were recorded by video (800 minutes in total). The category system resulting from a structured qualitative video analysis with a total of 568 codes contains design-, instruction- and interaction-related optimisation potentials for further development of the virtual learning sequence. Mistakes, difficulties and other anomalies during the application on the real machine provide further revision options. The study uses video data for the first time to derive optimisation potentials and to investigate the learning transfer of virtually learned action knowledge to the real-world activity.

Introduction

Immersive virtual reality technologies (IVR) have undergone a change in cost and dimensional factors and are now suitable for large-scale use since the first commercially viable virtual reality glasses were published in 2015 (Vergara, Rubio, & Lorenzo, 2017). Virtual reality (VR) refers to computer-generated real-time representations of real or fictional environments that are three-dimensional and interactive. Head-mounted-displays (HMDs) allow users to “immerse” themselves into these virtual environments (Freina & Ott, 2015).

The use of VR in vocational education and training—especially in technical domains—is associated with diverse potentials. VR can be used to simulate situations that would be excessively

Practitioner Notes

What is already known about the topic?

- A combination of quantitative and qualitative data for formative evaluation is feasible to improve the quality of virtual learning environments and maintain critical constructive feedback.
- Relevant aspects for evaluating virtual learning environments include usability, technology acceptance, motivation and learning efficiency.
- Different methods for measuring the learning efficiency of VR training exist, eg, subjective measures or pretests/posttests.

What this paper adds:

- An immersive virtual environment with its specific methodical-didactic concept is introduced.
- Video data are used for the first time to derive optimisation potentials in a formative evaluation. The procedure of extracting and analysing the data in a structured video analysis is introduced in the paper.
- Learning transfer of the virtually learned content to the real-world context of action is assessed and applied in the field of mechanical and plant engineering on a complex real machine for the first time.

Implications for practice and/or policy:

- The described methodical procedure using video analysis enables deriving design-, instruction- and interaction-related optimisation potentials.
- The results show that spatial information was transferred to the real machine without any issues, whereby the main difficulties appeared during steps that require haptic feedback.
- The use of IVR should be critically assessed due to the effort required in creation.

dangerous or expensive under physically real conditions or to reach places that are unreachable in reality; for example, because they are too far away or in the future or past. VR makes training possible without the need for real machines or equipment to be physically present. This flexibility offers an economic advantage by saving travel costs and preventing machine downtimes. Learning and working in virtual environments is safe, as there is no risk of damage to expensive equipment. Complex principles of a machine can be made easier to understand; for example, by making invisible processes visible (Jensen & Konradsen, 2018; Pantelidis, 1997; Pletz & Zinn, 2020; Potkonjak *et al.*, 2016; Vergara *et al.*, 2017).

The research project VASE[1] focuses on the use of IVR in the industrial service sector of mechanical and plant engineering and aims to design IVR training for operation training and examine it scientifically regarding the actual transfer process. This paper presents the formative evaluation of an immersive virtual learning scenario developed within the project using video analysis.

Theoretical background and state of research

In evaluations of virtual learning environments, besides the analysis of usability (Muller, Panzoli, Galaup, Lagarrigue, & Jessel, 2017; Satter & Butler, 2015), technology acceptance (Herz & Rauschnabel, 2019; Pletz & Zinn, 2018) and motivation (Guo, 2015), performance in real-world situations after the virtual training holds particular interest to evaluate their effectiveness. This aspect is referred to as learning or training transfer (Bossard, Kermarrec, Buche, & Tisseau, 2008; Rose, Attree, Brooks, Parslow, & Penn, 2000).

Transfer and learning theories

"Transfer of training is defined as the extent of retention and application of knowledge, skills and attitudes from the training environment to the workplace environment" (Bossard *et al.*, 2008, p. 1). The scientific interest in transfer goes back a long way in the research literature and includes different concepts of transfer and its recording (Cox, 1997; Day & Goldstone, 2012). Atherton (2007) summarises three generations of theories of transfer: (1) Behavioural approaches are based on the assumption that learning transfer can only take place if identical elements are present in the learning and application situation (eg, Thorndike & Woodworth, 1901). This means that the extent of learning transfer depends on how much agreement there is between the learning and application situation. (2) Cognitivist approaches, moreover, focus less on shared surface features of physical or task environments, but rather on information processing. Mental symbolic representations and cognitive schemata are seen as the basis for transfer (eg, Gentner, Loewenstein, & Thompson, 2003; Gick & Holyoak, 1983; Singley & Anderson, 1989). However, since the results of studies on transfer in the context of these approaches were inconsistent, surprising or sobering (Barnett & Ceci, 2002; Day & Goldstone, 2012; Detterman, 1993), the (3) third generation of approaches to transfer developed, which views transfer from a different perspective and not just as a direct application of knowledge in a new situation and its measurements in laboratory situations. To mention are, for example, the approach of Bransford and Schwartz (1999) on people's preparation for future learning, which shifts the focus of the consideration of transfer to the effects of new learning or the actor-oriented transfer perspective of Lobato (2003, 2012) which focused on whether learners recognise similarities across situations. The third generation can be placed in the general context of situational perspectives (Greeno, Collins, & Resnick, 1996).

Zinn and Ariali (2020) pointed out that the approach of situated learning (Lave & Wenger, 1991; Wenger, 1998) is particularly important for the conception of didactic designs in immersive virtual learning environments. The approach of situated learning is based on the assumption that cognitive learning processes always take place in a considered application context. Learning is effective when a situational reference to the professional and working world is established. In terms of transfer, this means that knowledge and skills are always tied to the context in which they were acquired. Situational learning can be supported, assuming that realistic IVR environments offer situations that trigger the same behaviour and the same thinking in learners as real situations (Loke, 2015). However, it has not yet been sufficiently clarified to what extent virtual experiences are actually comparable to real experiences and to what extend the natural user interfaces sufficiently support the visual and sensomotoric experiences (Zinn & Ariali, 2020).

Another important approach for IVR research is embodied cognition (Johnson-Glenberg, 2018; Zinn & Ariali, 2020). It assumes that physical states have an influence on cognition and human action (Glenberg, 2010; Núñez, Edwards, & Matos, 1999). Costa, Kim and Biocca (2013) cited different research findings that showed that cognitive representations of objects are intrinsically linked to how a person moves in order to manipulate the object. The use of the body can promote processing of abstract facts and understanding (Black, Segal, Vitale, & Fadjo, 2012; Lindgren, Tscholl, Wang, & Johnson, 2016). IVR requires users to move their bodies to interact with a virtual environment, to perform actions and to adopt different perspectives. In terms of embodied cognition, IVR offers the opportunity to create mental schemata of objects by manipulating them in virtual space through body movements and sensory input. With regard to the transfer from virtually learned to real activities, one can assume that this connection could facilitate actions on real objects. There are approaches that show that the body also plays an important role in situated learning processes and that the two theories complement each other (Rambusch & Ziemke, 2005).

IVR in the field of engineering

There are studies on the investigation of IVR environments in the field of engineering, but only a few with regard to their effectiveness in terms of a successful learning transfer. Brough *et al.* (2007) presented an IVR application for the training of assembly operations over a decade ago. In the study, the participants were asked to assemble the model of a real rocket or aircraft engine after virtual training. The results indicated promising potentials of the technology, as the majority of the participants successfully completed the task. A pilot study by Sportillo, Avveduto, Tecchia, and Carrozzino (2015) tested the extent to which the assembly of a real LEGO building set can succeed after an immersive virtual training. The results were positive, although they did not seem to be very reliable due to the small sample size ($N = 8$). Muller *et al.* (2017) developed an IVR learning environment for operator training of a CNC machine and analysed the user experience of the application using questionnaires. An investigation of the actual learning performance was not carried out. Im, An, Kwon, and Kim (2017) also tested an IVR environment for engine assembling and disassembling training. The aspects interest, immersion, satisfaction and perceived learning effectiveness were assessed by means of a questionnaire.

Methodological approaches of evaluation studies

Regarding the methodological approach, evaluation studies have shown that a combination of quantitative and qualitative approaches has proven favourable to obtain constructive feedback and increase the quality of the virtual learning environment (Bucher, Blome, Rudolph, & von Mammen, 2019; Han, 2019). On the one hand, aspects of usability, motivation or acceptance can be recorded in a standardised way through questionnaires. On the other hand, the systematic review by Radianti, Majchrzak, Fromm, and Wohlgenannt (2020) on the use of IVR in higher education showed that most of the reviewed studies do not specify a method for measuring learning outcome in their evaluation. Studies which have evaluated the learning effectiveness have used both subjective criteria, such as self-assessments using questionnaires and objective criteria, such as the time required to complete a task in reality after the virtual training, the number of errors, knowledge tests or judgements by experts (Bucher *et al.*, 2019; Bun, Trojanowska, Ivanov, & Pavlenko, 2018; Kamińska *et al.*, 2017; Zhang, Suo, Chen, Liu, & Gao, 2017). Measuring the effectiveness of VR through learning transfer can be challenging, since, as the above-mentioned discourse in transfer research shows, there are not only different views on the occurrence of a transfer, but also on its measurement (Barnett & Ceci, 2002; Bossard *et al.*, 2008; Reed, 2012; Singley & Anderson, 1989). Particularly in the field of mechanical and plant engineering, complex activities have to be carried out to operate a machine, which contain both declarative and procedural knowledge elements. Diverse, heterogeneous actions—for example, with different tools or on several components of a machine—must be learned. An objective measurement of the learning transfer by purely quantifying the errors or measuring the time required is not necessarily sufficient to obtain both a meaningful result and, if necessary, specific feedback to assess the learning environment. In addition, specific valid and reliable test instruments would have to be newly developed for the respective unique machine, to measure acquired knowledge of action by means of a test, which would involve an enormous research-economic effort. Another option would be to use only significantly simplified tasks to represent the activity; however they cannot grasp the full complexity of action. To our knowledge, no study to date in the field of mechanical and plant engineering has examined the learning transfer of learned action knowledge in a virtual learning environment with objective procedures on a real machine. The method of video analysis was used for the first time in this study to meet this research desideratum.

To date, the method of video analysis has been applied especially in studies on teaching and learning processes in school (Blikstad-Balas & Sorvik, 2014; Jacobs, Kawanaka, & Stigler, 1999; Stigler, Gallimore, & Hiebert, 2000). The main advantage of video analysis is the possibility to make work processes accessible in terms of their complexity—for example, to capture parallel events and make courses of action visible. Furthermore, situations can be repeatedly viewed from different perspectives and at different times (Derry *et al*., 2010; Jacobs *et al*., 1999). However, the data material also increases the effort required for evaluation. A theory-based, structured approach to analysis is, therefore, essential.

Description of the virtual learning environment

The immersive virtual learning environment created in VASE comprises a fully functional, 3D real-time, interactive model of a machine for the additive production of complex, metallic components in a virtual training building. The IVR application was created in Unity. Besides the basic functionality of Unity, the “SteamVR” framework was used. The application is optimised for use with the HTC Vive VR glasses, although it also works on the Oculus Rift. The 3D environment was created with the 3D software 3ds Max. For the machine display, the existing CAD data of the machine was prepared, made real-time capable and divided into learning modules. The other tools in the application were also created with 3ds Max using reference media (images, videos).

The goal of VASE is to conduct operation training with machine operators and service technicians on virtual machines. In the first step, a learning sequence in self-learning mode for operator training for the “removal of the construction cylinder” at the machine was developed (see Figure 1a–d). The removal of the construction cylinder must be carried out by the

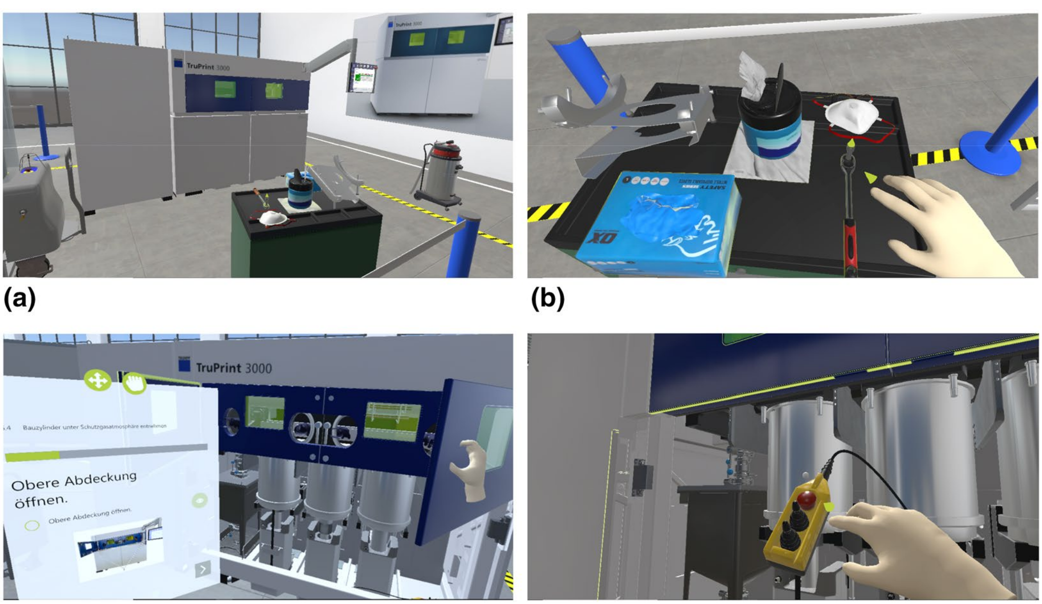

Figure 1: (a) – (d) Virtual learning sequence “removal of the construction cylinder”
[Colour figure can be viewed at wileyonlinelibrary.com]

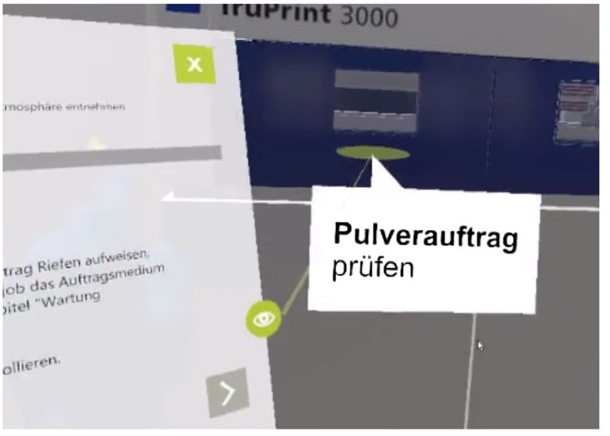

Figure 2: "Eye button" in the menu of the virtual learning sequence
[Colour figure can be viewed at wileyonlinelibrary.com]

machine operators after each printing of a component and involves a complex sequence of actions. For example, the construction cylinder must be moved into the correct position via the control panel, screws must be loosened and it must be removed with a lift truck. The virtual learning sequence comprises of a total of 36 instructed action steps, which are carried out by the learner on the virtual machine. It takes about 30 minutes to run through the sequence.

The learner receives all information about the process and all instructions—including visual material—via a menu (see Figure 1c), which is placed on the virtual left hand and audibly via the headphones of the VR glasses. If necessary, the menu can be minimised or freely placed in the room using interactive buttons with the help of the controllers; for example, if both hands are needed to perform an action step or if the menu would cover the field of vision. The menu contains a "checklist" and automatically checks off the individual steps as soon as the learner has performed them correctly. In the menu, there is also an "eye button" next to each action step (see Figure 2). With this button, the user can see which component the action step refers to and where it can be found. Via teleport, the learner can move around in the virtual environment. Interactions with virtual elements such as operating panel or tools are also carried out by the controllers. To introduce the training participant to the basic operation of VR hardware, a tutorial can be used in advance.

Research questions

The following exploratory research questions were addressed to improve the virtual learning sequence:

- Research question 1 (RQ 1): How is the immersive virtual learning sequence assessed in terms of technology acceptance, motivation, effort and user experience by potential machine operators?
- Research question 2 (RQ 2): To what extent can the action-related knowledge acquired in the immersive virtual learning sequence be transferred to real activity?

Methods

Research design

A formative evaluation was carried out in the present study to improve the developed virtual learning sequence and to identify potential for optimisation. The evaluation was conducted via a structured qualitative video analysis with video material from the virtual training and the subsequent testing phase. In addition, quantitative questionnaires were used to evaluate aspects of technology acceptance, motivation, physical and cognitive effort, user experience, and an assessment of subjective learning success.

The approach of a formative evaluation was chosen to continuously optimise the learning environment in the development process and was based on user feedback. According to Brown and Gerhardt (2002), this increases the prospect of a successful implementation of the defined goals, in this case the implementation of a beneficial immersive virtual learning environment. It differs from a summative evaluation in the sense that no finished product is examined. According to Tessmer (1993), formative evaluations can provide information about how effective, efficient, interesting/motivating, usable or acceptable an instruction is to improve instructional quality. The evaluation of effectiveness, ie, the question whether the learners will learn what we want them to learn, includes the successful or unsuccessful transfer of the virtually learned to reality for virtual learning environments (Bossard *et al*., 2008; Rose *et al*., 2000). Regarding the definition of a formative evaluation as an iterative process, the present study represents the first iterative step for the structured revision of the examined virtual learning sequence. According to the classification of transfer, we can speak of a near transfer in this study (Barnett & Ceci, 2002; Blume, Ford, Baldwin, & Huang, 2010; Bossard *et al*., 2008). Near transfer means applying the learned skills and knowledge in an almost identical situation. The learning outcome after a virtual training on a real machine is considered here, ie, the persons are supposed to apply the learned action-related knowledge in a situation that is identical in reality. In our understanding, a transfer is successful if the person correctly executes the learned steps on the real machine.

Participants

$N = 13$ persons participated in the evaluation study ($n = 9$ male and $n = 4$ female). The average age was 32.31 years (SD = 8.52 years) with a range from 21 to 53 years. According to Bucher *et al*. (2019), a heterogeneous sample is particularly suitable for formative evaluations to uncover optimisation potential that is as heterogeneous as possible and thus design the learning environment to suit the largest possible number of people. Therefore, in the present study $n = 6$ participants have learned technical professions such as tool mechanic, while the other respondents have learned non-technical professions such as vocational pedagogue. A total of 46 % ($n = 6$) of the test persons had never used the IVR technology prior to the study, 38 % ($n = 5$) had tried it once and one test person (8 %, $n = 1$) used it often or regularly. None of the test persons had any prior knowledge of the trained machine and none of the test persons had seen the machine live prior to the training.

Procedure of virtual training and data collection

The immersive virtual learning environment was evaluated in a learning and testing phase (see Figure 3). The participants were first informed about the process and instructed to memorise the training content well, since the learning success would be tested later. In the learning phase, the participants attended operator training using the IVR sequence in small groups of 3–5 persons. They first received a verbal introduction to the machine with explanations of the function and the basic components as well as safety instructions from a trainer. Subsequently, the trainer demonstrated the removal of the construction cylinder on the virtual machine once, whereby

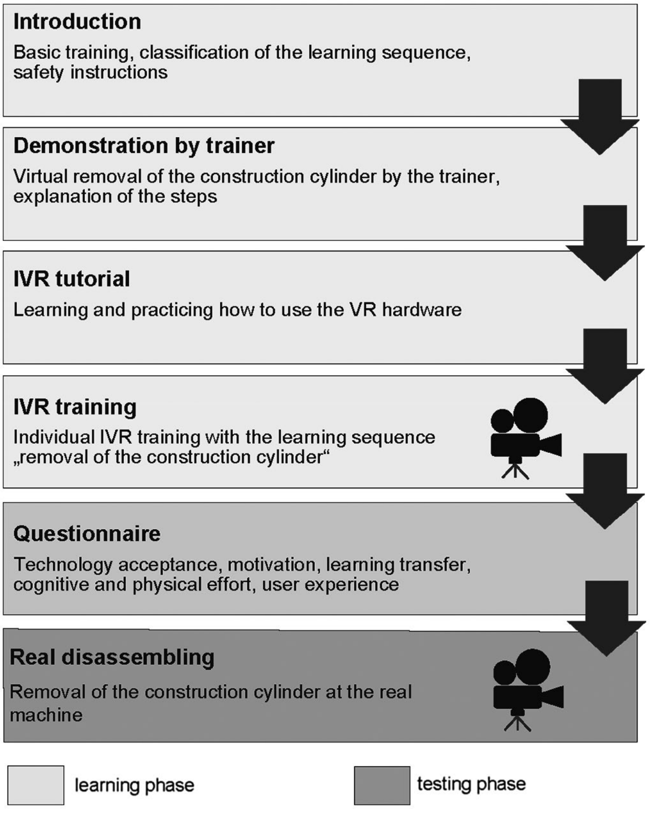

Figure 3: Schematic procedure of immersive virtual training and data collection

the test persons could follow the procedure on a screen. Afterwards, the participants were individually instructed in the use of the VR hardware. They used the IVR tutorial to learn the basic operating options such as teleporting, gripping and the menu operation. Finally, the test persons individually went through the virtual learning sequence for removing the construction cylinder. This was recorded on video and observation protocols were written.

After completing the virtual training, the participants answered the questionnaires. In the subsequent testing phase, they should transfer what they had learned virtually to the real machine and remove the construction cylinder. The participants had the opportunity to use the machine manual if they were unable to make any further progress with the removal by themselves. Since the machine manual can also be used in reality as first aid by the machine operators in the event of problems on the machine, this possibility was granted to the participants for a scenario that is as realistic as possible. In addition, a machine expert was present during the removal to intervene if the participant or the machine were endangered. The testing phase on the real machine was also recorded on video and observation protocols were written by the machine expert. Overall, the operator training as well as the completion of the questionnaires and the testing phase lasted about 3 hours for each participant. The time between the virtual training and testing phase was balanced for all participants, at about 4 hours.

Questionnaires

The technology acceptance of virtual training was surveyed according to the technology acceptance model (TAM; Davis, 1989; Pletz & Zinn, 2018) and included two items on the perceived usefulness (example item: "VR technology is useful for training"), and three items each on the perceived ease of use ($\alpha = 0.76$; example item: "Using VR technology was easy for me") and intention of use ($\alpha = 0.85$; example item: "I would like to use VR technology regularly for training in the future"). Following Kopp, Dvorak, and Mandl (2003), the motivation in the learning process ($\alpha = 0.78$; example item: "During the learning sequence in VR I experienced myself as interested") as well as the subjective assessment of the learning success ($\alpha = 0.79$; example item: "Through the virtual learning sequence I acquired enough knowledge to remove the construction cylinder from the real machine") was recorded by three items. The items were answered on a 7-point Likert scale (1 = "strongly disagree"; 4 = "partly agree"; 7 = "completely agree"). In addition, the level of physical and cognitive effort during the virtual training was recorded with one item each (example item: "How high was your physical effort during the learning unit in VR?"; 1 = "very low"; 7 = "very high"). The User Experience Questionnaire Short Version (UEQ) was used to record the user experience (Laugwitz, Schrepp, & Held, 2006). The participants ranked their impression on eight semantic differentials from the six categories of attractiveness, efficiency, comprehensibility, reliability, stimulation and novelty (example items: −3 = "complicated"; +3 = "easy").

Data analysis

The structured qualitative video analysis is oriented in its basic approach to Derry *et al.* (2010) and the structured qualitative content analysis according to Mayring (2014). It comprised the steps described below (see Figure 4):

1. *Viewing of the data material:* First, the videos from the learning and testing phase were completely viewed twice by an observer (a total of about 800 minutes of video material).
2. *Definition of the analysis unit*: According to the event sampling method (Boudah, 2011), the videos were divided into sense units and the occurrence of events within these units was observed. In contrast to this is the time sampling method, which divides the videos into time units. In the present videos, a unit was defined as an action step according to the correct procedure for removing the construction cylinder. According to our definition, a successful learning transfer of virtual learners on the real activity manifests itself in a "trouble-free" removal of the construction cylinder on the real machine. For this reason, every incident that deviates from this was initially regarded as an event. In the videos from the virtual training, these included errors in the execution of the IVR learning sequence (for example, the participant does not execute the instructed step correctly), comprehension difficulties (for example, the participant asks the trainer questions or verbally states that he does not know what to do), interaction difficulties (for example, the interaction with a virtual object does not work) and errors in the IVR application (for example, the application hangs up). The following events were recorded in the videos from the testing phase on the real machine: errors in execution (for example, a step is forgotten), difficulties in understanding or execution (for example, the participant asks the machine expert questions) and other anomalies.
3. *Transcription*: In addition to the events described under point 2, all verbal expressions of the participants, the trainer and the machine expert were transcribed. A second independent observer checked the transcripts for completeness in a further viewing process, and the observation protocols were used for cross-checking and in case of ambiguities.

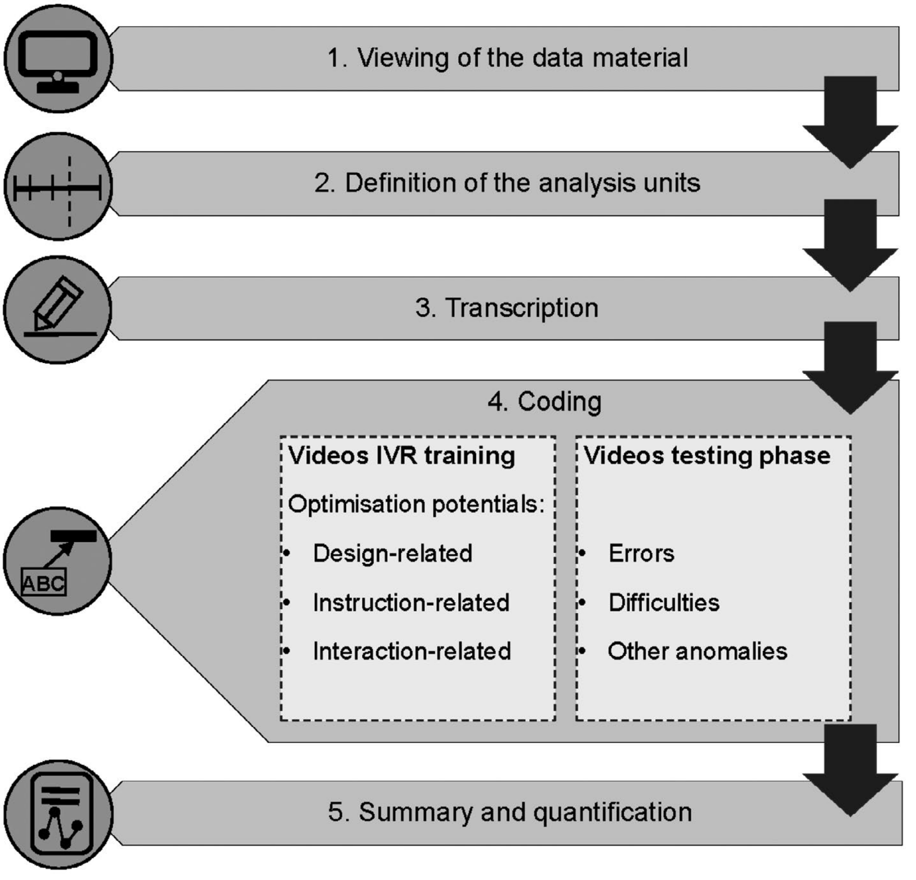

Figure 4: Schematic procedure of coupled video analysis to the immersive virtual training and testing phase (Vid-VR)

4. *Coding*: The next step was the coding and categorisation of the transcribed video units using the software MAXQDA (version 12). The category system developed for this purpose (see 1) comprises six deductively formed categories. Three of the categories refer to the video data from the IVR training: (1) design-related optimisation potentials, (2) instruction-related optimisation potentials and (3) interaction-related optimisation potentials. The other three categories represent the video data from the testing phase: (4) errors, (5) difficulties in understanding or execution and (6) other anomalies. Based on the category system and including the coding rules defined, the coding process was performed by a second independent person and the intercoder agreement (Cohen's kappa, k) was determined. In the literature, Cohen's kappa values greater than 0.6 are considered acceptable (Burla *et al.*, 2008; McPhail, Khoza, Abler, & Ranganathan, 2016). The interrater reliabilities of the present categories are thus all within a satisfactory range. A total of 568 codes were assigned in the analysis.
5. *Summary and quantification:* In a final step, the coded sequences within the categories were summarised and quantified to make statements about which events occurred across people and not only affected individuals. Due to the large diversity of events occurring between participants, a cut-off value of n = 4 persons was determined for all elements in the categories, with the exception of the design-related optimisation potentials. In the results of the

Table 1: Category system from the video analysis

Video	*Category*	*Definition*	*Codes*	*Cohen's kappa*	*Example (Video position*)*
IVR training	Design-related optimisation potential	**Errors** in the virtual environment OR there are difficulties in running the learning sequence due to the **technical design**, eg, the given physical properties of objects.	42	0.75	Step "Retract lift truck" is already checked in the menu, although it has not yet been fully executed (CJ1193_V1#21:47-22:10)
IVR training	Instruction-related optimisation potential	Difficulties or errors occur during the learning sequence due to the **instructions given** or the **absence of instructions**, eg, the person asks the trainer what to do.	151	0.66	Participant only removes the powder around the construction cylinder; trainer indicates that all powder in the process chamber must be removed (MJ0877_V1#04:00-04:10)
IVR training	Interaction-related optimisation potential	Difficulties occur in the learning sequence due to **interactions with virtual elements**, eg, when grasping objects or navigating. An action is only defined as an interaction problem if the person tries to perform the interaction more than twice.	107	0.78	Participant accidentally teleports behind the machine instead of picking up the manual control unit (AH0366_V2#04:08-04:12)
Testing phase	Errors	Action steps are **not carried out**, **incorrectly** or **in the wrong order** or the **wrong tool** is used.	109	0.83	Participant does not fully open the fastening nuts (SB1188_V3#01:30-02:00)
Testing phase	Difficulties	Difficulties in understanding or implementation arise, eg, the person asks the expert **questions**, **verbal statements** that he does not know what to do or how to do something or the expert has to provide independent **assistance**.	99	0.68	Ask the expert how the media plug can be solved (EG0190_V3#06:30-06:45)

Table 1: *(Continued)*

Video	*Category*	*Definition*	*Codes*	*Cohen's kappa*	*Example (Video position*)*
Testing phase	Other anomalies	**Other** remarks or actions of the persons, which do not fit into the above categories, but deviate from the trained sequence or a "trouble-free" sequence, eg, permissible sequence changes of the steps or other execution of the steps, which are not wrong.	60	0.84	Instead of the button with the curved arrow, the participant uses the button with the straight arrow to lower the construction cylinder on the control panel (MJ0877_V1#02:45-02:58)

*The video position comprises the six-digit alpha-numeric participant code, the video and the minutes in the video.

video analysis, therefore only results that occurred with at least four persons are reported. For the design-related optimisation potentials, a cross-person occurrence of the events is not relevant—for example—technical errors in the application do not necessarily occur with several people, but must be corrected in any case.

The quantitative data collected were evaluated descriptively with the statistics programme R (version 3.4.4).

Results

Quantitative analysis: Descriptive results

The usefulness of IVR in training (*median* = 5.55, IQR^2 = 1.50) and the ease of use of IVR (*median* = 6.00, *IQR* = 1.00) were rated as high. The intention to use IVR for training in the future was rated as medium to high (*median* = 5.00, *IQR* = 1.33). The results also show that the participants in IVR training experienced strong motivation in the learning process (*median* = 6.67, *IQR* = 0.67). The subjective assessment of the learning success is also high (*median* = 6.00, *IQR* = 1.67).

The physical effort in IVR training was rated by the participants as low to medium (*median* = 3.00, *IQR* = 2.00). The evaluation of mental effort can be placed in a medium range (*median* = 4.00, *IQR* = 3.00). The results from the UEQ can be seen in Figure 5 and indicate a consistently positive assessment of the user experience in the virtual learning sequence.

Qualitative analysis: Results from the video data

In the video analysis, design-related optimisation potentials (*N* = 7) were identified, which will be considered in the further development of the learning sequence to provide a technically perfect learning sequence.

The identified instruction-related optimisation potentials (*N* = 10) are needed in the further development process to sharpen the instructions for action and explanations in the learning sequence; for example, by providing additional information or visual aids for carrying out an

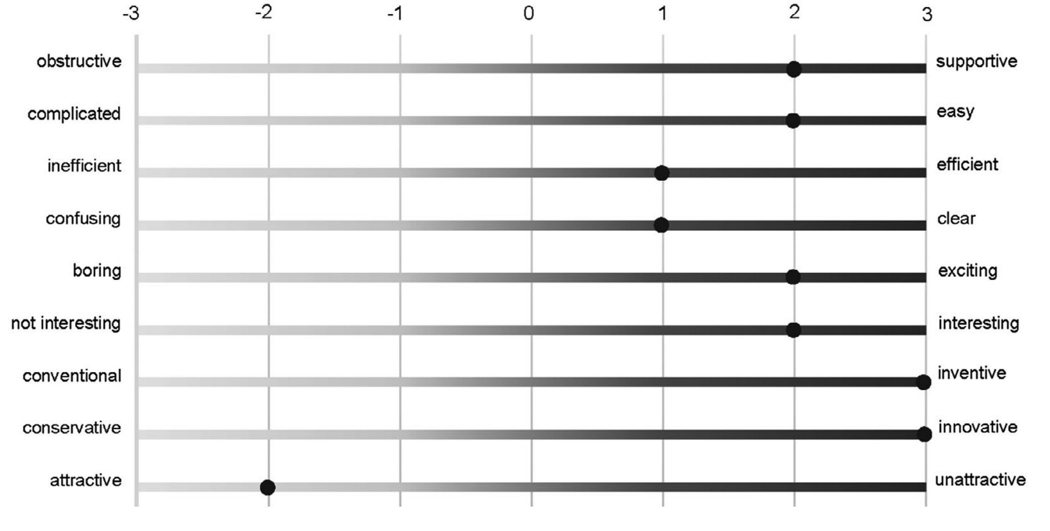

Figure 5: Results from the user experience questionnaire-short version (UEQ). Points represent the medians of the item

action step. Furthermore, based on these points, further illustrations or short video sequences of the real machine are incorporated as a basis for explanation to gain a better understanding of the processes.

With the interaction-related optimisation potentials identified ($N = 8$), there are approaches for adapting the tutorial; for example, by including certain interactions or practising them in depth. Moreover, individual interactions in the learning sequence itself can be simplified; for example, using predefined fixed axes of movement of virtual objects, visual aids to the interaction points or automated interactions by simply selecting the objects by pressing the controller buttons.

Regarding the question to what extent the action-related knowledge acquired in the immersive virtual learning sequence can be transferred to real activity, it was first considered how many steps were correctly performed on the real machine. Figure 6 shows that 23 of the 36 steps could be performed on the real machine without errors or difficulties for most participants. This shows, first of all, that most of the virtually learned action steps could be transferred to real activity. A closer look at the steps that led to problems allows further conclusions to be drawn about the possibilities for optimisation in the learning sequence and about general potentials and challenges for a learning transfer with IVR.

Various aspects can be derived from the errors that occurred in the removal of the construction cylinder on the real machine. Among the errors that occurred ($N = 9$), six errors are steps that were forgotten. A closer analysis of these steps reveals that these are either activities that involve a pure visual inspection of values—for example, the temperature at which the participants do not have to perform any "action"—and, therefore, they can be quickly processed in the IVR application by simply fixing components visually or activities that can be carried out at the touch of a button on the control. To support the memory performance, these steps should be emphasised more clearly in IVR; for example, by defined longer fixation times until the step is marked as completed or additional explanations why it is relevant. The other errors were steps that were performed incorrectly. Two of these errors were probably due to an inaccurate representation in the IVR application. For example, a marking on the lift truck for adjusting the forks was not exactly in the same place as at the real machine. These points can be systematically remedied in

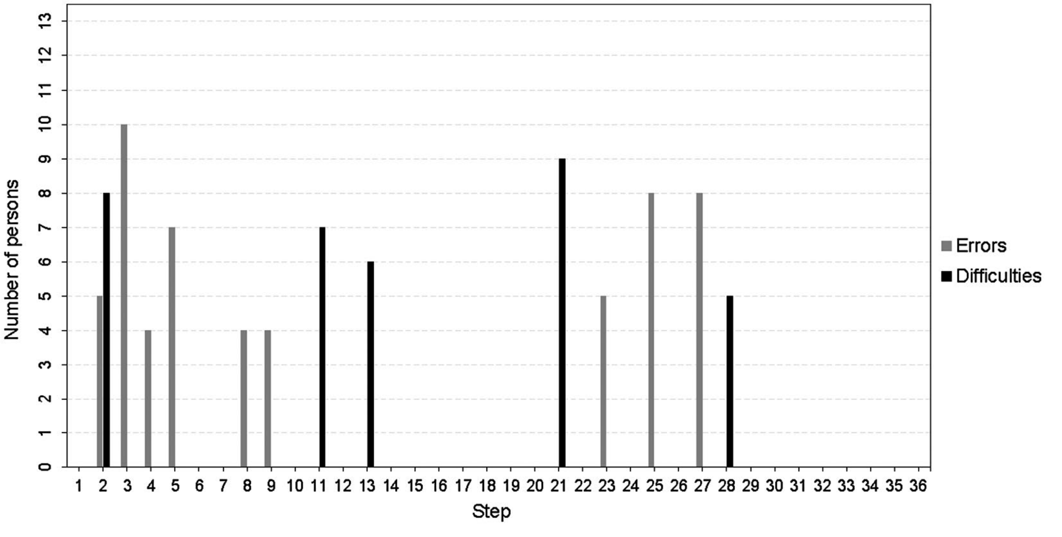

Figure 6: Overview of the errors and difficulties encountered in the individual steps

the design-related revision. Finally, an error probably occurred due to missing haptic feedback in the IVR application. The participants lacked the information concerning the extent to which the screws must be loosened.

The difficulties in understanding or execution identified in the videos of the testing phase at the real machine ($N = 5$) also primarily show problems with steps that require haptic feedback; for example, when removing the metal powder with a brush. They also provide further approaches for optimising the learning sequence through additional explanations or visual clarification.

It should be noted that no errors or difficulties were found regarding the spatial arrangement of the machine or the identification and location of components. However, during or after the testing phase some participants ($N = 4$) verbally expressed that they felt partially insecure on the real machine; for example, by asking the machine expert questions such as: "You'd step in before I broke something?" (CK0293_V1#17:05-17:15). The manual was also frequently used in the process of removal (*median* = 18.00, *IQR* = 9.00).

Further exploratory results from the video analysis

In the systematic analysis, it was noticed in the IVR learning phase that some participants very commonly used the "eye button" as a visual prompt to help them locate where the next step should be performed, although they had already been able to follow the entire sequence in advance with the trainer. This gave the impression that these participants were rather passively "shuffling" from step to step. There could be a risk that this would support a passive learning process (Bransford, Brown, & Cocking, 2000).

The correlation between the use of the eye button in virtual training and the number of errors and difficulties on the real machine was, therefore, analysed in further detail in the present study. Figure 7 shows a scatter diagram and indicates a positive correlation. It demonstrates, that overly frequent use of the "eye button" could make learners too passive in the learning process and thus the learning content is internalised less well, which is reflected in a higher error and difficulty rate at the real machine and thus a worse learning transfer. A closer look at the nature of the errors and difficulties encountered in video analysis on the real machine indicates that people with more frequent use of the eye button often forgot steps and regularly performed steps incorrectly in reality, or did not understand how to perform the step correctly and, therefore, needed the assistance of the expert. This finding can support the explanatory approach. However, this result should be evaluated carefully, taking into account the small sample size.

Summary and discussion

The present study aimed to formatively evaluate an immersive virtual learning environment for use in operator training for a machine from the additive manufacturing sector of mechanical and plant engineering. The focus was placed on how the immersive virtual learning sequence is assessed by potential users in terms of technology acceptance, motivation, effort and user experience (RQ 1), as well as the extent to which the action-related knowledge acquired in the immersive virtual learning sequence can be transferred to real activity (RQ 2). In our study, a structured qualitative video analysis (Vid-VR) was implemented for the first time and supplemented with quantitative questionnaires.

The quantitative descriptive results show a positive technology acceptance in terms of usefulness, ease of use and intention of use by the users, as well as positive assessments of the motivation in the learning process and learning success. The scales for user experience were all within a highly satisfactory range. The assessment of cognitive effort in VR training was positive and in a medium range. According to the assumptions of the cognitive load theory (Sweller, 1988), learning tasks

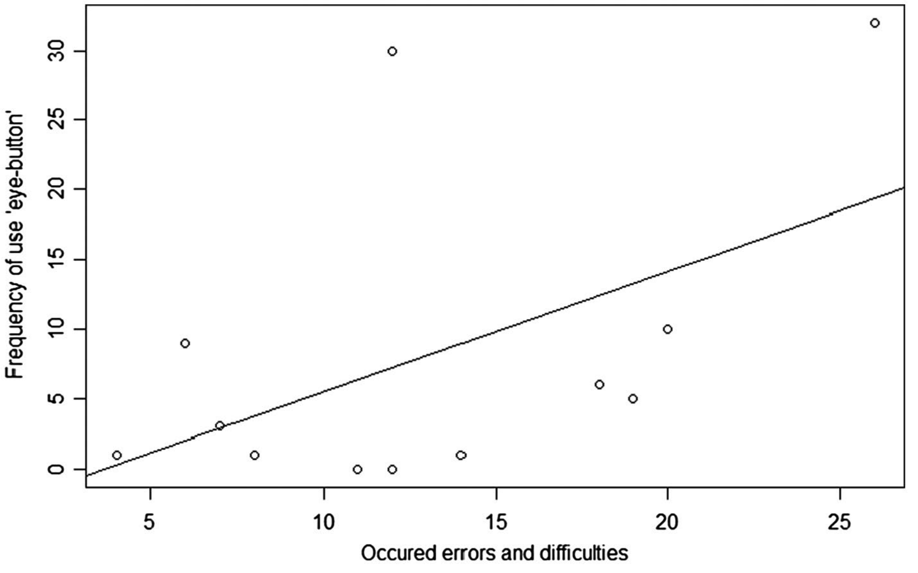

Figure 7: Correlation between the errors and difficulties occurring in the testing phase and use of the "eye" button in IVR training

that neither overstrain nor sub-challenge learners and thus produce a medium cognitive effort are ideal for challenging the cognitive resources of learners (Schnotz & Kürschner, 2007).

Various design-, instruction- and interaction-related optimisation potentials specific to VR applications could be systematically identified with the help of the category system developed in Vid-VR. The errors, difficulties and other anomalies on the real machine complement these further development possibilities and provide initial impulses for general statements on the use of IVR in technical operator training. Overall, the analysis shows that most of the steps learned to remove the construction cylinder in the immersive virtual environment were successfully transferred to the real machine. It should be particularly emphasised that the study confirmed a good understanding of spatial relationships as the primary advantage of VR, in line with other study results (Dalgarno & Lee, 2010; Fogarty, McCormick, & El-Tawil, 2017; Schnabel & Kvan, 2003). After the virtual training, the participants had no difficulties in correctly locating components or tools and orienting themselves spatially on the machine, which shows that especially the spatial aspects of virtual training could be successfully transferred to reality. However, it also became apparent that a flawless and realistic representation of the machine or the associated objects is essential for them to be recognised and for action steps to be correctly transferred to reality. In this context, it should be noted that the VR developer is usually not a machine expert and, therefore, close-meshed, iterative coordination processes are necessary until a technically correct result is achieved.

A further limitation of IVR for use in technical training courses is the limited haptic feedback. This, according to the available results, can make a transfer of the virtually learned into reality more difficult, since relevant information, such as how far a screw must be loosened, cannot be sufficiently provided. This limitation can be considered especially in the context of the training concept of IVR training (Zinn, Pletz, Guo, & Ariali, 2020). In particular, the experience of the target group with the corresponding required activities (eg, handling tools, previous knowledge of the machine) should be taken into account. On the one hand, a pure IVR training could be sufficient to impart action-related knowledge to experienced persons, since the basics for successfully transferring the actions to reality (eg, How do I handle a ratchet?) are already available. On the other hand, it may make more sense to offer a IVR training course for inexperienced persons following and in addition to a classroom training on the real machine to adequately convey the corresponding basics, which are necessary to enable a successful transfer for the learner despite limited haptics in IVR.

The final point to discuss is the exploratory result on the use of the "eye button." It suggests a possible correlation between (overly) frequent use of virtual help in the learning process and a lower learning transfer, which is reflected in a higher number of errors and difficulties in operating the real machine. This finding is supported by the results of Farrell *et al*. (2003), who showed in a study on route learning in desktop-based VR that the active participation of learners in navigation is essential to enable the transfer of a learned route in VR to a real environment. Subjects who were given a visual guide to help them navigate through a virtual building did not navigate through the real building better than a control group without training. Bransford *et al*. (2000, p. 53) stated that "transfer is best viewed as an active, dynamic process rather than a passive end-product of a particular set of learning experiences." Therefore, our findings might be explainable in terms of learning theory. For the conception of VR training, it should be ensured that the participants are actively involved in the learning process, which can be achieved—for example—through adaptive training to increase the probability of a successful transfer.

Limitations of the study result from the small sample size, which only allows a descriptive examination of the quantitatively surveyed scales and makes no claim regarding representativeness. Furthermore, the training was not real training of actual prospective machine operators, but rather a simulated training situation. However, there were no indications in our results of a lack of learning motivation in the sample, which is why this point can be neglected for the primary goal of optimising the IVR learning sequence. For research-economic reasons, especially due to the limited test time, only self-assessments were obtained for individual constructs, without resorting to complete and standardised instruments.

The present contribution aimed at developing and testing the video analysis-based evaluation method Vid-VR. No control group was used in the formative evaluation that would have allowed a comparison of the learning transfer with a conventional (classroom) training. Further studies should, therefore, aim at a summative evaluation of the revised virtual learning environment and examine the acceptance, motivation and learning performance in an experimental control group design in comparison with conventional classroom training. Ideally, the virtual learning environment should be used in a real training situation to gain feedback from the actual target group. The potential lack of confidence at the real machine after a purely virtual training should be surveyed as an explicit investigation variable. Furthermore, the exploratory result on the use of the "eye button" offers potential approaches for a more precise analysis of the extent to which such virtual aids support or inhibit an active learning process among participants.

In summary, this paper addresses the research desideratum after evaluation studies on virtual learning environments in the technical field. The methodical approach using video analysis can offer a useful basis for other research groups as it seems to be easily transferable and specifically extendable to further IVR applications to evaluate virtual learning environments and meet the challenges involved, such as an objective measurement of learning transfer.

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Statement on open data, ethics and conflict of interest

Due to data protection legislation, the video data used for this study cannot be made publicly available. The quantitative datasets used and analysed are available from the authors on reasonable request.

The study was undertaken in line with institutional ethics procedures and guidelines. Research participants gave informed consent on the video recording.

There was no conflict of interest in this research.

Notes

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[2] IQR = Interquartile range.

References

Atherton, M. (2007). *A proposed theory of the neurological limitations of cognitive transfer*. Presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin*, *128*(4), 612–637.

Black, J. B., Segal, A., Vitale, J., & Fadjo, C. (2012). Embodied cognition and learning environment design. In D. Jonassen & S. Lamb (Eds.), *Theoretical foundations of student-centered learning environments* (pp. 198–223). New York: Routledge.

Blikstad-Balas, M., & Sorvik, G. O. (2014). Researching literacy in context: Using video analysis to explore school literacy. *Literacy*, *49*(3), 140–148.

Blume, B. D., Ford, J. K., Baldwin, T. T., & Huang, J. L. (2010). Transfer of training: A meta-analytic review. *Journal of Management*, *36*(4), 1065–1105.

Bossard, C., Kermarrec, G., Buche, C., & Tisseau, J. (2008). Transfer of learning in virtual environments: a new challenge? *Virtual Reality*, *12*(3), 151–161.

Boudah, D. J. (2011). *Conducting educational research: Guide to completing a major project*. Thousand Oaks, CA: Sage Publications.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academic Press.

Bransford, J. D., & Schwartz, D. L. (1999). Rethinking transfer: A simple proposal with multiple implications. *Review of Research in Education*, *24*, 61–100.

Brough, J. E., Schwartz, M., Gupta, S. K., Anand, D. K., Kavetsky, R., & Pettersen, R. (2007). Towards the development of a virtual environment-based training system for mechanical assembly operations. *Virtual Reality*, *11*, 189–206.

Brown, K. G., & Gerhardt, M. W. (2002). Formative evaluation: An integrative practice model and case study. *Personnel Psychology*, *55*(4), 951–983.

Bucher, K., Blome, T., Rudolph, S., & von Mammen, S. (2019). VReanimate II: Training first aid and reanimation in virtual reality. *Journal of Computers in Education*, *6*(1), 53–78.

Bun, P., Trojanowska, J., Ivanov, V., & Pavlenko, I. (2018). The use of virtual reality training application to increase the effectiveness of wokshops in the field of lean manufacturing. In *The 4th International Conference of the Virtual and Augmented Reality in Education* (pp. 65–71). Budapest, Hungary.

Burla, L., Knierim, B., Barth, J., Liewald, K., Duetz, M., & Abel, T. (2008). Form text to codings: Intercoder reliability assessment in qualitative content analysis. *Nursing Research*, *57*(2), 113–117.

Costa, M. R., Kim, S. Y., & Biocca, F. (2013). Embodiment and embodied cognition. In R. Shumaker (Ed.), *Virtual augmented and mixed reality. Designing and developing augmented and virtual environments* (pp. 333–42). Berlin, Heidelberg: Springer.

Cox, B. D. (1997). The rediscovery of the active learner in adaptive contexts: A developmental-historical analysis of transfer of training. *Educational Psychologist*, *32*(1), 41–55.

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–32.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, *13*(3), 319–340.

Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist*, *47*(3), 153–176.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., … Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *Journal of the Learning Sciences*, *19*(1), 3–53.

Detterman, D. K. (1993). The case of the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Norwood, NJ: Ablex Publishing.

Farrell, M. J., Arnold, P., Pettifer, S., Adams, J., Graham, T., & MacManamon, M. (2003). Transfer of route learning from virtual to real environments. *Journal of Experimental Psychology: Applied*, *9*(4), 219–227.

Fogarty, J., McCormick, J., & El-Tawil, S. (2017). Improving student understanding of complex spatial arrangements with virtual reality. *Journal of Professional Issues in Engineering Education and Practice*, *144*(2), 1–10.

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. In *eLearning and Software for Education (eLSE) Conference Proceedings* (pp. 1–8). Bucharest, Romania.

Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A genereal role for analogical encoding. *Journal of Educational Psychology*, *95*(2), 303–408.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychologist*, *15*, 1–38.

Glenberg, A. (2010). Embodiment as a unifying perspective for psychology. *Wiley Interdisciplinary Reviews: Cognitive Science*, *4*(1), 586–596.

Greeno, J. G., Collins, A. M., & Resnick, L. B. (1996). Cognition and learning. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 15–46). New York: Macmillan.

Guo, Q. (2015). Learning in a mixed reality system in the context of 'Industrie 4.0'. *Journal of Technical Education (JOTED)*, *3*(2), 92–115.

Han, I. (2019). Immersive virtual field trips in education: A mixed-methods study on elementary students' presence and perceived learning. *British Journal of Educational Technology*, *15*(2), 420–435.

Herz, M., & Rauschnabel, P. A. (2019). Understanding the diffusion of virtual reality glasses: The role of media, fashion and technology. *Technological Forecasting & Social Change*, *138*, 228–242.

Im, T., An, D., Kwon, O.-Y., & Kim, S.-Y. (2017). A virtual reality based engine training system: A prototype development & evaluation. In *Proceedings of the 9th International Conference on Computer Supported Education (CSEDU 2017)* (pp. 262–267). Porto, Portugal.

Jacobs, J. K., Kawanaka, T., & Stigler, J. W. (1999). Integrating qualitative and quantitative approaches to the analysis of video data on classroom teaching. *International Journal of Educational Research*, *31*(8), 717–724.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*, 1515–1529.

Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI*, *5*(81), 1–19.

Kamińska, D., Sapiński, T., Aitken, N., Della Rocca, A., Barańska, M., & Wietsma, R. (2017). Virtual reality as a new trend in mechanical and electrical engineering education. *Open Physics*, *15*(1), 936–941.

Kopp, B., Dvorak, S., & Mandl, H. (2003). *Evaluation des Einsatzes von Neuen Medien im Projekt „Geoinformation - Neue Medien für die Einführung eines neuen Querschnittfachs"* (Forschungsbericht Nr. 161) [Evaluation of the use of new media in the project "Geoinformation - New media for the introduction of a new cross-sectional subject" (Research report 161)]. München: Ludwig-Maximilians-Universität.

Laugwitz, B., Schrepp, M., & Held, T. (2006). Konstruktion eines Fragebogens zur Messung der User Experience von Softwareprodukten [Construction of a questionnaire to measure the user experience of a software product]. In A. M. Heinecke & H. Paul (Eds.), *Mensch & Computer 2006: Mensch und Computer im Strukturwandel [Man and Computer 2006: Man and computer in structural change]* (pp. 125–134). München: Oldenbourg.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within mixed reality simulation. *Computers & Education*, *95*, 174–187.

Lobato, J. (2003). How design experiments can inform a rethinking of transfer and vice versa. *Educational Researcher*, *32*(1), 17–20.

Lobato, J. (2012). The actor-oriented transfer perspective and its constributions to educational research and practice. *Educational Psychologist*, *47*(3), 232–247.

Loke, S. K. (2015). How do virtual world experiences bring about learning? A critical review of theories. *Australasian Journal of Educational Technology*, *31*(1), 112–122.

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. Klagenfurt: Beltz.

McPhail, C., Khoza, N., Abler, L., & Ranganathan, M. (2016). Process guidelines for establishing intercoder reliability in qualitative studies. *Qualitative Research*, *16*(2), 198–212.

Muller, N., Panzoli, D., Galaup, M., Lagarrigue, P., & Jessel, J.-P. (2017). Learning mechanical engineering in a virtual workshop: A preliminary study on utilisability, utility and acceptability. In *IEEE (Chair), 9th International Conference on Virtual Worlds and Games for Serious Applications* (pp. 55–62). Athens, Greece: IEEE.

Núñez, R., Edwards, L. D., & Matos, F. J. (1999). Embodied cognition as grounding for situatedness and context in mathematics education. *Educational Studies in Mathematics*, *39*, 45–65.

Pantelidis, V. S. (1997). Virtual reality and engineering education. *Computer Applications in Engineering Education*, *5*(1), 3–12.

Pletz, C., & Zinn, B. (2018). Technology acceptance of virtual learning and working environments in technical domains. *Journal of Technical Education (JOTED)*, *6*(4), 86–105.

Pletz, C., & Zinn, B. (2020). An explorative study on potential applications of VR in technical domains. In B. Zinn (Ed.), *Virtual, Augmented und Cross Reality in Praxis und Forschung: Technologiebasierte Erfahrungswelten in der beruflichen Aus- und Weiterbildung - Theorie und Anwendung [Virtual, augmented and cross reality in practice and research: Technology-based experience worlds in vocational education and training – Theory and application]* (pp. 115–40). Stuttgart: Franz Steiner Verlag.

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, *95*, 309–327.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778.

Rambusch, J., & Ziemke, T. (2005). The role of embodiment in situated learning. In *Proceedings of the 27th Annual Conference of the Cognitive Science Society* (pp. 1803–1808). Mahwah, NJ: Lawrence Erlbaum.

Reed, S. K. (2012). Learning by mapping across situations. *The Journal of the Learning Sciences*, *21*(3), 353–398.

Rose, F. D., Attree, E. A., Brooks, B. M., Parslow, D. M., & Penn, P. R. (2000). Training in virtual environments: Transfer to real world tasks and equivalence to real task training. *Ergonomics*, *43*(4), 494–511.

Satter, K., & Butler, A. (2015). Competitive usability analysis of immersive virtual environments in engineering design review. *Journal of Computing and Information Science in Engineering*, *15*, 1–12.

Schnabel, M. A., & Kvan, T. (2003). Spatial understanding in immersive virtual environments. *International Journal of Architectural Computing*, *4*(1), 435–448.

Schnotz, W., & Kürschner, C. (2007). A reconsideration of cognitive load theory. *Educational Psychology Review*, *19*(4), 469–508.

Singley, M. K., & Anderson, J. R. (1989). *The transfer of cognitive skills*. Cambridge: Harvard University Press.

Sportillo, D., Avveduto, G., Tecchia, F., & Carrozzino, M. (2015). Training in VR: A preliminary study on learning assembly/disassembly sequences. In L. T. de Paolis & A. Mongelli (Eds.), *International Conference on Augmented and Virtual Reality AVR 2015* (pp. 332–343). Switzerland: Springer International Publishing.

Stigler, J. W., Gallimore, R., & Hiebert, J. (2000). Using video surveys to compare classrooms and teaching across cultures: Examples and lessons from the TIMMS video survey. *Educational Psychologist*, *35*(2), 87–100.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285.

Tessmer, M. (1993). *Planning and conducting formative evaluations: Improving the quality of education and training*. London: Psychology Press.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review*, *8*, 247–261.

Vergara, D., Rubio, M. P., & Lorenzo, M. (2017). On the design of virtual reality learning environments in engineering. *Multimodal Technologies and Interaction*, *1*(11), 1–12.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge: Cambridge University Press.

Zhang, K., Suo J., Chen, J., Liu, X., & Gao, L. (2017). Design and implementation of fire safety education system on campus based on virtual reality technology. In *IEEE (Chair), Proceedings of the Federated Conference on Computer Science and Information Systems (FedCSIS)* (pp. 1297–300). Prague, Czech Republic.

Zinn, B., & Ariali, S. (2020). Technology-based experience worlds - Teaching and learning between virtuality and reality. In B. Zinn (Ed.), *Virtual, Augmented und Cross Reality in Praxis und Forschung: Technologiebasierte Erfahrungswelten in der beruflichen Aus- und Weiterbildung - Theorie und Anwendung [Virtual, Augmented and Cross Reality in practice and research: Technology-based experience worlds in vocational education and training – theory and application]* (pp. 13–30). Stuttgart: Franz Steiner Verlag.

Zinn, B., Pletz, C., Guo, Q., & Ariali, S. (2020). Conceptual design of virtual teaching and learning arrangements in the context of the industrial service industry of machine and plant engineer. In B. Zinn (Ed.), *Virtual, Augmented und Cross Reality in Praxis und Forschung: Technologiebasierte Erfahrungswelten in der beruflichen Aus- und Weiterbildung - Theorie und Anwendung [Virtual, augmented and cross reality in practice and research: Technology-based experience worlds in vocational education and training – theory and application]* (pp. 169–184). Stuttgart: Franz Steiner Verlag.