IADIS International Journal on WWW/Internet
Vol. 21, No. 1, pp. 1-17
ISSN: 1645-7641

THE CHALLENGES, POTENTIALS AND EXPERIENCES OF VIRTUAL REALITY LEARNING UNITS

Thomas Keller, Stefan Botchkovoi, Elke Brucker-Kley and David Grünert
ZHAW Institute of Business Information Technology
Winterthur, Switzerland

ABSTRACT

Immersive Virtual Reality has become a mature technology. The development environments are stable and advanced as for other deployment platforms. Hardware has reached a price level that is affordable for educational institutions, at least for developed countries. However, practical experiences with virtual reality are still limited compared to other hardware used in schools. Pedagogy and didactics have only started to include the new possibilities of virtual reality into their repertoire. Therefore, it is not astounding that literature shows a rather heterogenous picture of the practical use, the pros and cons of immersive virtual reality. The first part of this paper gives an introduction into the research field of immersive virtual reality including a summary of VR worlds, their potentials and challenges. The second part disseminates the findings of two field studies with immersive virtual reality. One study happened at an undergraduate course of a university of applied science. The second study was performed at two different primary schools. Both studies aimed at the learning impact. Both studies used A/B testing to demonstrate any difference compared to standard approaches. And both studies weren't able to show a significant improved learning success. However, both learning units were able to activate students and to trigger at least for a short term a higher interest in the subject matter. If joy and pleasure are considered important for learning virtual reality is an added value.

KEYWORDS

Virtual Reality, Education, Field Experiment

1. INTRODUCTION

Digital media such as tablets or smartphones are already part of daily life for many children. They watch movies, play games or communicate with their friends. The children actively and self-determinedly participate in their digital world with their possibilities and competencies. Virtual worlds such as Minecraft are discovered by children in a self-determined and creative way (Baek et al., 2020; Callaghan, 2016). In these virtual worlds, children tackle challenges, experiment with virtual objects, or discover numerous phenomena (Cramariuc & Dan, 2021; Villena Taranilla et al., 2022). These are promising alternatives to initiate sustainable learning processes, provide children with appropriate experiential and learning opportunities in digital learning environments, and foster competencies in the digital environment (Best et al., 2019). But how can these virtual experiential and learning opportunities be designed in the subject classroom to provide children with guidance in their digital world? How can digital media be used to design new teaching and learning processes in a way that creates opportunities for individual competence development?

Extracurricular venues are particularly suitable for enabling students to experience a living world that is not accessible to them in everyday life (Salzmann, 2007). The use of virtual environments in primary education has been little researched so far. Various authors estimate the potential for successful learning as high (Buchner, 2022; Hellriegel & Čubela, 2018). Digital worlds enable a variety of experiential and learning opportunities that create new and inclusive support opportunities both outside and inside school (Bakenhus et al., 2022). In the context of technological development, virtual reality (VR) can promote skills and constructivist learning beyond subject matter knowledge. But field studies don’t always show a positive impact on learning success(Keller et al., 2020; Keller & Botchkovoi, 2022; Keller & Brucker-Kley, 2021). VR technology is increasingly used in various learning environments to reduce complex teaching topics and present realities in a structured and immersive way (Radianti et al., 2020).

2. RESEARCH OBJECTIVE AND APPROACH

Immersive VR applications are not yet widely used in the school context (Pirker et al., 2020). A possible reason for this could be a lack of strategies and concepts for media development and integration of the technology into the teaching process (Hellriegel & Čubela, 2018; Martín-Gutiérrez et al., 2017). Hellriegel & Čubela (2018) suggest that the rapid development of the technology is the reason for the low user rates. Therefore, there are a limited number of scientific publications dealing with virtual reality in education and its didactic use (Kröner et al., 2021). Little research has been done on how to integrate VR into curriculum and instruction, so collaboration between educators and game developers is needed for future studies (Berger, Martin et al., 2022; Martín-Gutiérrez et al., 2017; Pirker et al., 2020).

From this, the following three research questions can be derived, which the literature research and field study documented here aims to answer:

RQ1: Does VR contribute to students' knowledge transfer?

RQ2: Does learning success be increased with the help of VR learning units compared to classic learning units?

RQ3: What criteria are relevant when developing and using VR learning units in order to use the full potential of VR?

This scientific work is based on the Design Science approach according to Hevner et al. (2004). The basic principle of Design Science Research is that knowledge and understanding of a design problem and its solution are acquired through the creation and application of an artifact (VR Learning Unit). A systematic literature review will examine the topic of VR and how it relates to pedagogy and didactics. Specific content will be selected from the literature that deals with immersive VR in an educational context. In addition, further pedagogical, didactical requirements and content will be developed together with teachers in order to incorporate them into the optimization of the two VR learning units. The development and optimization of the artifacts is oriented towards evolutionary prototyping (Bischofberger & Pomberger, 1992).

To determine the learning success of the VR learning units, qualitative field experiments with A/B testing (Döring & Bortz, 2016) were conducted. The target group of the VR learning unit and the field experiment are middle school students of elementary and secondary schools and undergraduate students respectively. The measurement of knowledge gain is implemented with the help of a pre- and post-survey. For this purpose, questionnaires were designed, which is filled out by all groups before and after the completion of the learning unit.

3. VR LEARNING WORLDS

The possibility of realizing convincing representations in VR initially leads to the assumption that these visualizations stimulate learning (Gerth & Kruse, 2020). However, as with any other medium, didactic considerations and learning activities are crucial for VR (Berger, Martin et al., 2022; Dede, 2009; Keller et al., 2020; Kerres, 2013, 2018), there are the following learning-related action options for VR learning worlds:

1. **Exploratory worlds**: They aim to impart declarative knowledge and enable learners to engage with virtual environments independently and exploratively. Coupled with activating learning tasks, such as creating mind maps, such worlds can be effective in building new knowledge structures (Parong & Mayer, 2018).
2. **Experimental worlds**: In this way, the laws of physics can be suspended and causal relationships can be investigated (Schwan & Buder, 2006).
3. **Training worlds**: Here, learners practice and train skills and abilities that are not feasible in real environments, for example, because they are too dangerous, too expensive, or not feasible at all. Such worlds are already frequently used in vocational training, for example in the automotive industry or in the training of prospective painters (Berger, Martin et al., 2022; Zender et al., 2020).
4. **Construction worlds**: Learners can independently create their own objects or even entire virtual worlds in these worlds. They are still rarely used in education, partly because their production is particularly technically demanding (Radianti et al., 2020).

In summary, learning with VR is motivating, entertaining, and varied. Especially when actively participating and interacting with the virtual world, various studies show better cognitive experiences and enhanced learning effects (Freina & Ott, 2015; Jensen & Konradsen, 2018; Krokos et al., 2019; Maas & Hughes, 2020). The reason is that learning is more emotional and immersive, adding relevance to the content. Critical reservations nevertheless remain, as long-term studies and large-scale field studies in particular are lacking (Keller et al., 2020; Radianti et al., 2020).

VR applications have the potential to increase learning success and promote constructive learning (Chavez & Bayona, 2018; Hellriegel & Čubela, 2018; Parong & Mayer, 2018). Furthermore, with the help of VR, difficult and risky training experiences (e.g., in medical and military practice) can be learned virtually. As a result, the cost of training and the potential risk of the real physical situation can be reduced. Furthermore, students can experience places and situations in the world that they would not otherwise be able to experience, enriching their learning experience (Reynard, 2017; Zender et al., 2020).

From a procedural point of view learning can have several orientations and characteristics:

1. **Learning as a self-directed process:** According to Arnold (2015), Reinmann-Rothmeier & Mandl (1997) and Shuell (1986), active participation of the learner is required. Without a self-directed share, sustainable learning growth cannot be achieved. Many teaching media and materials can only meet this requirement to a limited extent. VR applications basically allow more interaction or construction than classical media (Freina & Ott, 2015; Martín-Gutiérrez et al., 2017; Schwan & Buder, 2006). From a constructivist-didactic perspective, virtual worlds become significant only when learners can move freely in the virtual worlds to explore the learning objects at their own pace and freely construct viewpoints. This has the advantage that different types of learners can be addressed equally (Berger, Martin et al., 2022; Hellriegel & Čubela, 2018; Schwan & Buder, 2006). Furthermore, VR can change the way a learner interacts with the learning material. VR assumes interaction. It encourages active participation rather than passivity. The learner who interacts with the virtual environment is encouraged to continue the interaction by seeing the results immediately (Pantelidis, 2009). Thus, high learning success can be achieved especially when learners can make their own decisions based on the results of their own actions to achieve the goals they set for themselves (Hellriegel & Čubela, 2018; Zender et al., 2020).
2. **Learning as a productive and motivating process:** Enthusiasm, motivation and emotions can be seen as important factors for learning success (Keller et al., 2020). However, in order to promote the intrinsic motivation of learners, it is necessary to tie in with the learners' lifeworld, interests, and individual initial situations (Siebert, 1991). In particular, the advantage of VR applications is that they address multiple sensory channels (Schwan & Buder, 2006), make complex issues tangible (Köhler et al., 2013), and can provide learners with freely selectable courses of action to ideally make self-directed decisions and explore virtual worlds (Martín-Gutiérrez et al., 2017). In a meta-study, Freina & Ott (2015) point out that a clear link can be established between virtual technologies and the promotion of learner motivation. Martin-Gutierrez et al. (2017), Pantelidis (2009), and Vogel et al. (2006) also point to a relationship between VR and learner motivation (Hellriegel & Čubela, 2018).
3. **Learning as a situational and practice-related process:** Schüßler & Thurnes (2005) describe learning as a systematic, situational, and largely "self-organized appropriation process." Bailenson et al. (2008) highlight the potential of VR to address topics in the classroom that would be either too expensive or too dangerous in a real, physical environment. This expands the range of experiences that can be gained. Even complex and abstract relationships, as well as concepts and issues that are difficult to convey in normal settings, can be made vivid through VR. Schwan & Buder (2006) also speak of "metaphorical visualizations" in this context. The advantage of this visualization is that the learning object is given a concrete context, i.e., a concrete scenario, and authentically designed learning environments are created (Berger, Martin et al., 2022; Köhler et al., 2013). Learners can view complex subject matter from a first-person perspective and make concrete connections in a physical presence (Martín-Gutiérrez et al., 2017). Similarly, they can feel present in a virtual body that is not their own body but can be perceived as such (Bailenson et al., 2008).

4. **Learning as a social process:** In schools, cooperative learning is often used to impart knowledge. In this interactive and structured form of learning, it is assumed that students learn more through interaction than through individual work (Fürstenau & Gomolla, 2009; Reinmann-Rothmeier & Mandl, 1997). Reinmann, among others, refer to learning as a social process because it is an interactive exchange and is also subject to sociocultural influences.

Virtual environments offer the potential for interaction and collaboration among learners and foster discussion and feedback processes (Martín-Gutiérrez et al., 2017; Youngblut, 1998). A virtual environment can also be set up for multiple real people. An example can be teachers as tutors who can monitor behavior and learning progress and provide immediate feedback (Schwan & Buder, 2006). However, the extent to which VR offerings can be used for social interaction and communication depends heavily on the didactic objective of the particular offering. A discussion in the group after the application or even during the application are further possibilities for interaction and collaboration between learners. Whether a joint VR unit is useful, however, depends on the didactic objective (Hellriegel & Čubela, 2018).

4. POTENTIALS

VR is well suited for explaining complex issues (Berger, Martin et al., 2022; Checa & Bustillo, 2020; Christ & Hirschi, 2021; Pirker et al., 2020). Like a workshop, students are encouraged to think actively and create their own experiences. With VR learning units, the acquisition of a wide variety of competencies, such as strategic problem-solving orientation, is possible. Learning in a shared virtual reality can reveal ways in which collaboration and problem solving work in practice (Reynard, 2017). Thus, according to Hellriegel and Čubela (2018), VR learning units show potential for increasing learning success as well as promoting constructivist learning. Scenarios can also be acted out using simulations.

Hellriegel and Čubela (2018) evaluate the learning effect and potential of VR based on four surveyed principles for successful learning. The evaluations are confirmed by Zender et al. (2018), among others, who used brainstorming sessions with subject matter experts to determine the impact of VR for teaching and learning settings.

Niedermeier and Müller-Kreiner (2019) conducted surveys in 2018 and 2019 with 124 students from Bavarian universities regarding their assessment of VR and AR (augmented reality) technologies. The study was based on the question of how the students intend to use the technologies in their everyday studies in the future. At the time, the students surveyed were studying to become teachers, mainly in the fields of education, psychology and economics. The surveys revealed that the students knew what VR was. However, they showed little knowledge regarding learning scenarios that used VR or AR. The application of the technologies was rated as low by the students. It was striking that they stated that they had already used VR glasses more often than the far more accessible AR apps. Niedermeier and Müller-Kreiner (2019) concluded that students are not yet aware of the already widely established integration of AR even on mobile devices. According to the survey, the students surveyed consider it useful to use the two technologies as a supplement in didactic learning. The basis for these assessments was not investigated. Finally, the respondents were asked about their assessment of future learning. It became clear that digital media play a central role. However, the respondents were rather pessimistic about the regular use of VR and AR in everyday study in the next 10 years. Nevertheless, the survey showed that topics such as VR and AR would become more future-oriented in the next 50 years and would increase in terms of assessed importance. Students were also asked about their aspirations. The use of VR and AR technologies as supplementary learning methods was hardly mentioned. Interactive and individual learning was desired by the majority. Since VR and AR are said to have great potential to increase the learning success of students, Niedermeier and Müller-Kreiner (2019) recommend a didactically sensible variety of media with integration of VR and AR. An increased dialog with students can capture the needs for the optimal use of the media (Niedermeier & Müller-Kreiner, 2019).

A further assessment of the use of VR in everyday study was made by the ZHAW, the International Association of Lake Constance Universities (IBH) and the Lake Constance Graduate School (HTWG). By means of teaching projects, several teaching sequences were designed and implemented using VR systems. The aim of the projects was to develop evaluation criteria of possible uses of VR systems based on different teaching scenarios at the undergraduate level. The projects showed that the identification of suitable teaching scenarios proved to be difficult and the development laborious. Knaack et al (2019) estimates that the use of VR in teaching is not yet sufficiently efficient, given the high costs, the time required for programming, and the still unclear benefits. This is also confirmed by (Keller et al., 2020; Keller & Brucker-Kley, 2021). Knaack et al (2019) recommend increasing the number of usefully applicable scenarios and making these scenarios available on a cross-university platform for continuous further development.

In a systematic literature review, Pirker et al. (2020) investigated the potential and application of VR for computer science education. For this purpose, they identified learning objectives, interaction properties, and challenges and advantages of using immersive VR learning units for computer science education and extracted recommendations for action. For example, for an improved learning effect, it is recommended to incorporate interaction, immersion, visualization, game-like design, use of metaphors and analogies, and social experiences within the virtual environments (Pirker et al., 2020). In a systematic review of the literature, Hellriegel et al. (2018) adopt the constructivist view to evaluate the potential of VR in the classroom. According to Liu et al. (2017), constructivism places learners at the center of learning and teaching. In this view, students are actively involved in processing information and constructing objects under the guidance of teachers. Hellriegel et al. (2018) recommend that teachers not only design the content selection of VR learning units due to the different scenarios and possibilities for action, but also consciously control didactic potentials with regard to students' possibilities for action and participation. To this end, teachers must be adequately trained (Hellriegel & Čubela, 2018).

According to Pirker et al. (2020), educational media with a high degree of technological immersion positively influence the engagement, presence, and motivation of students. Stimulating student motivation can additionally be done by means of interesting and age-appropriate stories on the topic. In order for the VR experience to be seen by students as more than just a playful element, the immersive experience must be embedded in the instructional sequence. This can be achieved by aligning the virtual environment with learning objectives. A side effect of using VR technologies is cybersickness. Pirker et al. (2020) recommend using teleportation as a method of locomotion, which can prevent nausea and dizziness when using immersive VR learning sessions. In addition, lecturers need to be present when using the VR applications to support students and possibly offer other tasks if cybersickness cannot be overcome. This is also confirmed by Hellriegel and Čubela (2018) in their study. From Pirker et al.'s (2020) study, it appears that integrating an introductory phase with a simple example program can eliminate possible uncertainties among users. In doing so, students can familiarize themselves with the controls. According to Pirker et al. (2020), the design of VR scenarios is thus not limited to complex issues, but can be applied to a wide variety of topics. (Baniasadi et al., 2020) suggest that learning scenarios should be developed in such a way that they can be repeated as often as desired. It should also be considered that regular and immediate feedback is given when scenarios are completed to encourage the user (Baniasadi et al., 2020).

5. CHALLENGES

VR has a number of weaknesses from technological, organizational, and psychological perspectives (Velev & Zlateva, 2017). As a result, VR applications are currently used by educators with hesitation (Zender et al., 2018). For example, more powerful VR systems that also require a high-performance computer are costly.

Another challenge is the implementation effort. The implementation of VR applications is demanding. Increasingly complex program logics and support for different end devices complicate application development (Velev & Zlateva, 2017). Implementation cannot be done by teachers or computer scientists alone, as knowledge in programming, graphic design, pedagogy, and educational psychology is required (Liu et al., 2017; Pantelić & Vukovac, 2017).

The current generation of VR still offers much potential for development (Zender et al., 2018). A major shortcoming of VR is the lack of haptic feedback generation, which makes it impossible to simulate resistance, elasticity, structure, and temperature (LaValle, 2016). Gloves with force feedback capabilities are an active research field (Guo et al., 2021; Le & Nguyen, 2021).

VR input and output devices usually appear with their own SDKs, which are strongly tied to the corresponding hardware. These vendor-specific solutions make integration into existing systems and switching to other end devices difficult (Velev & Zlateva, 2017). Open standards such as VRPN or OSVR have not yet been able to establish themselves. However, often at least the most common development environments such as Unity or Unreal are supported, which have already proven themselves as leading development environments for VR and AR (Anthes et al., 2016).

In addition to the aforementioned technical and organizational challenges, it is important to consider the challenges specific to education. The enthusiasm for VR learning applications is currently boosted by a large novelty effect. However, this will decline and is subsequently insignificant for the actual effectiveness of learning tools (Keller et al., 2020).

One of the main challenges of VR learning applications is the currently scarce conceptual didactic basis (Berger, Martin et al., 2022; Zender et al., 2018). Many standard works on media didactics lack explicit treatment of VR. Furthermore, Akçayır & Akçayır (2017) point out the following additional challenges that limit learning experiences using VR:

- high time requirements,
- unsuitable for large groups, and
- possible cognitive overload of learners and
- misdirected attentional focus.

The use of VR requires media competence from teachers and learners. Learners must first master the use of the medium. The acquisition of these competencies is currently still severely hampered by the variety of devices, bulky head-mounted displays as well as counterintuitive user interfaces and insufficient assistance in connection with hardly binding standards. Teachers must also be able to operate the learning media and deal with error messages (Castellanos & Pérez, 2017).

Other factors hindering the use of VR applications in education include health concerns such as nausea, dizziness, and eye pain, which can be especially prevalent when using VR (LaViola et al., 2017). This can be attributed to conflicting sensory impressions (Hettinger & Riccio, 1992). Furthermore, immersive VR can create intense illusions, the physiological and psychological effects of which are difficult to assess (Zender et al., 2018).

When developing a VR learning unit, cognitive overload must be avoided. According to Liu et al. (2017), this must be taken into account both in the design of the scenes and in the organization of the learning materials. The challenge is to align with the learners' cognitive process. For example, the number and arrangement of objects in the environment as well as the learners' level of knowledge must be taken into account. The organization and presence of pluralistic media, such as sound or animation, must also be considered. In addition, reducing repetitive delivery of information can help conserve cognitive resources (Liu et al., 2017).

6. THE SUN, THE EARTH AND THE MOON

For this field experiment, the learning effect and the essential criteria for the use of virtual reality are investigated in a qualitative field experiment with a virtual reality learning unit about our solar system at primary school level. The development and optimization of the learning unit (Figure **1**) will not be discussed further in this paper. All documentation for this as well as the executables for Android-based (Quest2) and Windows-based systems (HTC Vive) are available at (Keller & Botchkovoi, 2022).

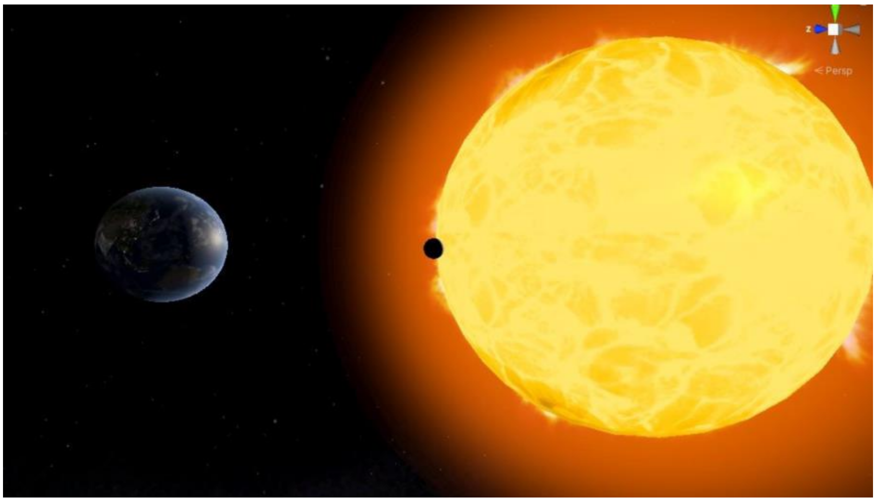

Figure 1. A glimpse from the learning unit

The qualitative field experiment took three school days to complete. The qualitative field experiment was conducted with one class each at a secondary school and an elementary school. The participating subjects were randomly divided into two subject groups. One group of subjects received the teaching content by means of the VR learning unit and the other group of subjects by means of a classical frontal teaching, in which the teachers were allowed to choose the teaching form and techniques freely. The raw data of the survey are also available at https://osf.io/t4sxj/.

The data collected from the pre- and post-measurement are analyzed and considered separately due to the different performance levels of the school classes (Figure 1 and 2). A total of 31 participants took part in the field experiment. Of these, eight participants were from the Realschule (secondary school), shown in Figure 1, and 23 from the Primarschule (elementary school), shown in Figure 2.

For both schools, an increase in knowledge can be seen for each group. It can be stated that in both cases the increase in knowledge was greater for the control group than for the VR group. This result is also consistent with the authors' experience from previous field experiments (Keller et al., 2020). A hypothesis for this is that the unfamiliar learning environment overloads the subjects' cognitive resources with the VR challenges. Repeated use of VR as a learning medium would alleviate this situation.

The execution of the VR learning unit as well as the frontal teaching were observed and recorded in order to gain further, primarily qualitative insights into the use of VR in an educational context. At the elementary school, eleven subjects were randomly assigned to conduct the VR learning unit. Before beginning the VR learning unit, subjects were asked questions in advance about their feelings and prior knowledge regarding VR and gaming. It was interesting to note that five of the eleven subjects had already played with VR sets more than once. One subject even plays with VR sets on a regular basis. All participating subjects received instruction. Subjects who already have regular contact with VR sets were quickly familiar with the controls and did not need any assistance. They used teleportation and additionally moved around using the movement buttons. Full attention could be paid to exploring the VR environment and working through the learning and task stations. Subjects who had no previous experience with VR used either only teleportation or only walking in the first scene. Combining both was too challenging for the subjects. Throughout the execution of the VR learning session, VR-inexperienced subjects were highly focused on the controls and somewhat less focused on the content. All subjects were able to complete the learning station and tasks independently. Subjects particularly enjoyed the throwing stations in the Earth and Moon scene. The learning content in the Journey to the Moon scene caused amazement, especially when the subjects saw the size relationships of the sun, earth, and moon. One subject perceived the VR learning unit more as a game and focused more on the playful aspect. Little attention was paid to the learning and task stations. All subjects were able to immerse themselves in the VR learning unit. A sense of presence was felt, which can be attributed to the immersive nature of the VR learning unit. In places, it was not possible to converse with the subjects during the execution because they were too shielded from the real world. The two youngest subjects, aged nine, had severe problems with their coordination. This resulted in wobbly legs and near falls. To continue the VR learning session, the subjects were given a chair to sit on. This measure minimized the coordination problems and even prevented them completely after a certain period of time. One of the affected subjects discontinued the VR learning session due to the occurrence of dizziness and nausea. The subject who regularly plays with VR sets devoted his full attention to the VR learning unit. In the pre-test, 25.5 points were already achieved. In the post-test, the subject achieved 31.5 out of 34 points.

After the field experiment was completed, the students from the control group were also allowed to play the VR learning unit to reward their use. It was observed that the students experienced an "aha effect". This means that the test subjects subsequently understood what they had previously learned from the frontal instruction. When asked, the students were able to confirm that they were able to better comprehend the size ratio of the sun, earth and moon in particular and gained an idea of the dimensions.

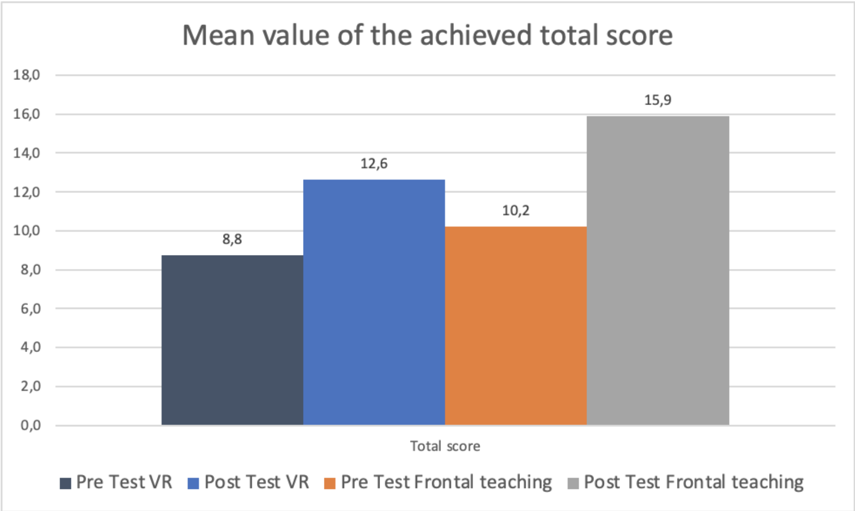

Figure 2. Average score for Realschule

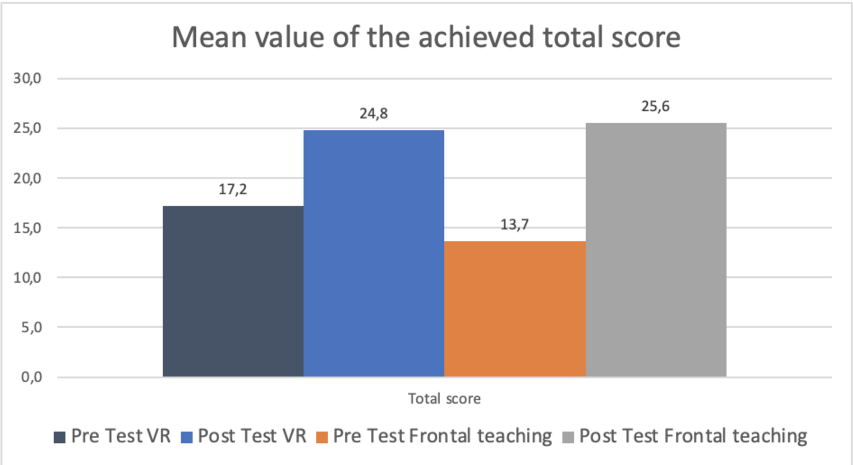

Figure 3. Average score for elementary school

The evaluation and interpretation of the data from the field experiment show that an increase in knowledge was achieved in all subjects of subject group VR (RQ1). This is shown by the key figures of the achieved score per question. These conclusions can be drawn for all subjects of the VR group when comparing the individual performances.

A direct comparison of the groups of test subjects shows that the control group performed better at both schools (RQ2). This is shown by the evaluation of the achieved total score of the test groups of both schools. Abstract questions about contents that are difficult to comprehend, which could be presented vividly by means of VR, could not be answered more successfully by the subjects of the subject group VR of both schools than by the control groups. It should be noted that small subject groups, can cause biases, for example, due to the personal attitude and motivation of individual subjects towards learning and the field experiment. With such small subject groups, this confounding variable cannot be reduced or eliminated by randomization. No robust conclusions about learning success through VR can be drawn from the collected elementary and secondary school data and findings alone. For this, further field experiments would have to be conducted at several schools and with larger subject groups, which is why the second research question cannot be answered conclusively. Nevertheless, the results show the tendency that the learning success with the help of VR learning units cannot be increased compared to classical learning units.

7. THE ROUTER PERSPECTIVE

For this field experiment, a virtual reality learning unit for explaining a router is created, optimized according to quality criteria and evaluated regarding the learning effect whereby the didactic approach of a change of perspective makes optimal use of the advantages of virtual reality and should enable a more profound understanding (Keller et al., 2022). Explaining complex issues such as components of the Internet can be difficult despite the use of models. Since the receptivity of people varies, different methods are usually required in education at the university level until a profound understanding is achieved (Christ & Hirschi, 2021). For example, explaining how a router works can be done theoretically, visually, as well as practically. Thus, an initial understanding can be developed by means of a picture and theory. By programming a routing table, a more profound understanding is aimed at. According to Christ and Hirschi (2021), the combination of teaching methods is an effective and popular way at universities to convey complex issues. However, the learning effort for students is usually underestimated. The will to persevere on the part of the students is assumed. Using VR to explain a complex subject, such as a router, offers the opportunity to improve the learning process by combining theory with visualization. Experiencing an algorithm represents a change of perspective, which is still little used at university level according to Pirker et al. (2020).

The learning effect of using a VR application to introduce and explain a router is evaluated using a quantitative randomized field experiment according to Döring and Bortz (2016). Subjects are randomly divided into test and control groups for later comparison (control group design). In this field experiment, the test group trains with the VR learning unit and the control group trains with the conventional conceptual description of the network components with text and images. The training is conducted under guidance and observation.

For optimal testing of the effect hypothesis, a repeated-measures design according to Döring and Bortz (2016) is chosen in this paper. Here, the dependent variable is measured before the intervention (pretest) and after the intervention (posttest), whereby the same samples are examined several times.

The combination of repeated measures and control group design results in the randomized pre-post control group comparison as a typical experimental design (Döring & Bortz, 2016).

The VR learning unit for explaining a network as well as a router was evaluated by 26 ZHAW students in the Bachelor's degree program in Business Information Technology. The majority (80%) of the respondents have no computer science background. Before and after testing, the subjects filled out a semi-structured questionnaire with semi structured questions (Curcio, 2022). Thus, the learning effect could be determined retrospectively. The detailed survey results are provided at (Curcio, 2022).

For testing, half of the subjects were presented with the VR learning unit, the other half with the theoretical preparation. In order to accompany the subjects during the execution, the students were assigned in groups of four. While two students were able to carry out the study with the theory on their own, the other two subjects were mainly accompanied in getting to know the VR learning unit and the corresponding interaction concept with the controllers. Students of the test group, who acquired the knowledge about routers purely theoretically, were offered to play through the VR learning unit as well after completing the questionnaires. All accepted this offer, which shows the curiosity and acceptance towards VR learning units.

Table 1 shows an evaluation of all tests before the knowledge transfer by means of the VR learning unit and the theory. To determine possible learning effects, the questionnaires of both groups were evaluated both before and after the knowledge transfer by means of the VR learning unit or the theory. A normal distribution of the sample is assumed. Thus, despite the rather small number of subjects of 26, trends can be described as to whether the VR learning unit leads to a learning effect. This will then be put in relation to the control group.

Table 1. Aggregated pre and post test results and comparison of the test group with the control group regarding the learning impact

	Correct answers concerning network functions	Correct answers concerning router functions	Combined learning impact for network and router functions
Test group (VR) pretest	60%	30%	n/a
Test group (VR) posttest	75%	55%	45%
Control group pretest	45%	30%	n/a
Control group posttest	90%	80%	125%

A measurable learning effect could be ascertained with the use of the VR learning unit based on the field study. The evaluated survey results show a learning effect of 45% after using the VR learning unit. The learning effect after the use of the theoretical preparation was also evaluated. The learning effect of 125% is much higher than the learning effect with the use of the VR learning unit. From this it can be deduced that the sole use of a VR learning unit is not advantageous. It will probably be more beneficial to include a VR learning unit as an additional offering in the curriculum.

It is assumed that the highest learning effect is achieved with the use of the theoretical preparation followed by the use of the VR application. Thereby, it is important to define learning objectives, as well as corresponding questions for each task within the VR learning unit that can be asked after using the application. By answering the questions, the learning objectives can be verified. The learning objectives and the associated questions provide a summary for the students and contribute to the orientation of the learning content. The results from the study and the high demand show that the router use case is a suitable choice for a VR learning unit in higher education.

Another deduction from this field study result is that as long as VR must be considered new and challenging for the subjects the learning effect is negatively affected. Even if help is provided within the VR learning unit the subjects were reliant on help from the instructor. Which means that instructors with a profound knowledge of the learning units need to be available on site. Apart from that instructors need to have also a technical understanding of the VR infrastructure to solve technical problems which are ever present as long as the maturity of the technology is in its current state.

During the field study it was further observed that subjects of the VR learning unit showed signs of fatigue after 30 minutes. A longer learning unit is not recommended for students at bachelor level.

However, VR learning units show great potential for consolidating acquired knowledge. Above all, the change of perspective from the viewer to the performer makes it easy to deepen what has been learned. VR learning units should not be seen as an alternative, but as a supplement to classic teaching methods. If VR learning units are used in this way, they can find great use in teaching.

8. CONCLUSION

Relevant criterias to consider when developing and using VR learning units to realize the potential of VR can be found from the literature review and the collected evidence from the observations of qualitative field experiments. Compelling representations in VR related to immersion and presence stimulate students to learn and increase motivation. The assumption that presence in a VR learning environment enhances memory processes cannot be clearly confirmed by means of the collected data. Immersion in VR environments is associated with a high cognitive load. This was observed irrespective of the age. Going through the VR learning unit caused coordination problems for the youngest subjects. This was noticeable by trembling legs, which led to near falls. The cognitive load can be reduced by instruction in the correct use of VR and further assistance, such as a seat and orientation aids by the teacher. Furthermore, the high cognitive load leads to learners concentrating too much on the controls and the didactic learning content being pushed into the background. To counteract this, the learners must be trained in advance in the use of the interaction possibilities. The observations show that learners who frequently play computer games in their free time do not have any advantages in dealing with VR. This was also observed for other field studies (Keller et al., 2020). For learners with little or no VR experience, there is a risk of motion sickness in the form of nausea and dizziness. Again, the risk of motion sickness can be mitigated by providing guidance in the use of VR glasses and using them regularly. The possible occurrence of eye pain was not noted, which can be attributed to the high resolution of the HMD. Learners with a fundamental VR experience can devote their concentration to the learning content to be taught. Nevertheless, care must be taken with experienced learners to direct their attention to the essentials, the learning content, as they tend to focus on the playful aspect of the technology. From the observations, VR-experienced learners are not prone to health impairments such as motion sickness.

VR learning content must build on existing subject matter knowledge. Further observations showed that learners with existing prior knowledge were better able to comprehend e.g., the size relationships and interrelationships of the solar system after completing the VR learning unit. Analogously, the same effect holds true for the router learning unit. The VR learning unit deepened the prior knowledge. Therefore, VR technology can be most effectively used as a supplementary medium in the school day. Based on the results of this work, it is recommended to follow the instructional design according to Mulders et al. (2020) for the use of VR technology as a learning opportunity.

Although the pitfalls of using VR in an educational context are known and although best practices are recommended to avoid them VR is only scarcely used despite its potential irrespective of the school level. Based on our experience after performing several field studies we argue that an operational model is the missing crucial piece. An operational model defines responsibilities, necessary organizational units, minimum skills with respective continuous education plans and an investment roadmap. This all is missing but crucial for a sustainable and effective integration of VR in a daily routine. The recent years have shown a tremendous investment in virtual meeting hardware and software that was accompanied by demanding new skills for teachers, lecturers and students. Existing IT support units had to cope with the new reality and they mostly succeeded. A comparable effort is needed for the introduction of VR. However, it is questionable if this will happen during the next years.

REFERENCES

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Anthes, C., García-Hernández, R. J., Wiedemann, M., & Kranzlmüller, D. (2016). State of the art of virtual reality technology. *2016 IEEE Aerospace Conference*, 1–19. https://doi.org/10.1109/AERO.2016.7500674

Arnold, R. (2015). Wie man lehrt, ohne zu belehren. 29 Regeln für eine kluge Lehre. Das LENA-Modell. Carl-Auer Verlag.

Baek, Y., Min, E., & Yun, S. (2020). *Mining Educational Implications of Minecraft: Computers in the Schools: Vol 37, No 1*. https://www.tandfonline.com/doi/full/10.1080/07380569.2020.1719802

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context. *Journal of the Learning Sciences*, *17*(1), 102–141. https://doi.org/10.1080/10508400701793141

Bakenhus, S., Holzapfel, M. A., Arndt, N., & Brückmann, M. (2022). Die Erstellung einer Lernumgebung mit immersiver Virtual Reality für das Fach Sachunterricht nach dem M-iVR-L Modell. *MedienPädagogik: Zeitschrift für Theorie und Praxis der Medienbildung*, *47*, 76–93. https://doi.org/10.21240/mpaed/47/2022.04.04.X

Baniasadi, T., Ayyoubzadeh, S. M., & Mohammadzadeh, N. (2020). Challenges and practical considerations in applying virtual reality in medical education and treatment. *Oman Medical Journal*, *35*(3), e125.

Berger, Martin, Kraus, K., Keller, T., Brucker-Kley, E., & Knaack, R. (2022). Virtuelle Lernumgebungen in der betrieblichen Ausbildung – eine Analyse am Beispiel der Elektrobranche in der Schweiz—Bwp@ Berufs- und Wirtschaftspädagogik—Online. https://www.bwpat.de/ausgabe/43/berger-etal

Best, A., Borowski, C., Büttner, K., Freudenberg, R., Fricke, M., Haselmeier, K., Herper, H., Hinz, V., Humbert, L. (federführend), Müller, D., Schwill, A., & Thomas, M. (2019). *Kompetenzen für informatische Bildung im Primarbereich*. http://dl.gi.de/handle/20.500.12116/20121

Bischofberger, W. R., & Pomberger, G. (1992). Paradigms for Software Development. In W. R. Bischofberger & G. Pomberger (Eds.), *Prototyping-Oriented Software Development: Concepts and Tools* (pp. 8–32). Springer. https://doi.org/10.1007/978-3-642-84760-8_2

Buchner, J. (2022). Generative learning strategies do not diminish primary students' attitudes towards augmented reality. *Education and Information Technologies*, *27*(1), 701–717. https://doi.org/10.1007/s10639-021-10445-y

Callaghan, N. (2016). Investigating the role of Minecraft in educational learning environments. *Educational Media International*, *53*(4), 244–260. https://doi.org/10.1080/09523987.2016.1254877

Castellanos, A., & Pérez, C. (2017). New Challenge in Education: Enhancing Student's Knowledge through Augmented Reality. In *Augmented Reality* (pp. 273–294). De Gruyter. https://doi.org/10.1515/9783110497656-015

Chavez, B., & Bayona, S. (2018). Virtual Reality in the Learning Process. In Á. Rocha, H. Adeli, L. P. Reis, & S. Costanzo (Eds.), *Trends and Advances in Information Systems and Technologies* (pp. 1345–1356). Springer International Publishing. https://doi.org/10.1007/978-3-319-77712-2_129

Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications*, *79*(9), 5501–5527.

Christ, O., & Hirschi, M. (2021). Virtual Reality in der Berufsbildung. Pilotstudie der login Berufsbildung AG und der Hochschule für Angewandten Psychologie (FHNW). https://doi.org/10.26041/fhnw-3588

Cramariuc, G., & Dan, M.-A. (2021). Integration of Virtual Reality in the Instructive-Educational Process in Primary Education. *Revista Romaneasca Pentru Educatie Multidimensionala*, *13*(1Sup1), Article 1Sup1. https://doi.org/10.18662/rrem/13.1Sup1/384

Curcio, R. (2022). *Router Learning Unit*. https://osf.io/tvd86/

Dede, C. (2009). Immersive Interfaces for Engagement and Learning. *Science*, *323*(5910), Article 5910. https://doi.org/10.1126/science.1167311

Döring, N., & Bortz, J. (2016). *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften* (5. vollständig überarbeitete, aktualisierte und erweiterte Auflage). Springer.

Freina, L., & Ott, M. (2015, April 1). A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives. *Conference: ELearning and Software for Education (ELSE)*.

Fürstenau, S., & Gomolla, M. (Eds.). (2009). *Migration und schulischer Wandel: Unterricht*. VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-91724-5

Gerth, S., & Kruse, R. (2020). VR/AR-Technologien im Schulungseinsatz für Industrieanwendungen. In H. Orsolits & M. Lackner (Eds.), *Virtual Reality und Augmented Reality in der Digitalen Produktion* (pp. 143–179). Springer Fachmedien. https://doi.org/10.1007/978-3-658-29009-2_8

Guo, Y., Yang, X., Wang, H., Zhang, Y., Xu, W., & Wang, D. (2021). Five-Fingered Passive Force Feedback Glove Using a Variable Ratio Lever Mechanism. *Actuators*, *10*(5), Article 5. https://doi.org/10.3390/act10050096

Hellriegel, J., & Čubela, D. (2018). Das Potenzial von Virtual Reality für den schulischen Unterricht-Eine konstruktivistische Sicht. *MedienPädagogik: Zeitschrift Für Theorie Und Praxis Der Medienbildung*, 58–80.

Hettinger, L. J., & Riccio, G. E. (1992). Visually Induced Motion Sickness in Virtual Environments. *Presence: Teleoperators and Virtual Environments*, *1*(3), 306–310. https://doi.org/10.1162/pres.1992.1.3.306

Hevner, A., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. MIS Quarterly, 28 (1), 75–105.

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*(4), Article 4. https://doi.org/10.1007/s10639-017-9676-0

Keller, T., & Botchkovoi, S. (2022). *Sonne-Erde-Mond*. https://osf.io/t4sxj/

Keller, T., & Brucker-Kley, E. (2021). Experiences with Virtual Reality at Secondary Schools: Is There an Impact on Learning Success? In D. Ifenthaler, D. G. Sampson, & P. Isaías (Eds.), *Balancing the Tension between Digital Technologies and Learning Sciences* (pp. 77–94). Springer International Publishing. https://doi.org/10.1007/978-3-030-65657-7_5

Keller, T., Brucker-Kley, E., & Ebert, N. (2020). The Use of Virtual Reality at Lower Secondary Schools. In P. Isaias, D. G. Sampson, & D. Ifenthaler (Eds.), *Technology Supported Innovations in School Education* (pp. 15–32). Springer International Publishing. https://doi.org/10.1007/978-3-030-48194-0_2

Keller, T., Curcio, R., & Brucker-Kley, E. (2022). The Value of Virtual Reality As A Complementary Tool For Learning Success. CELDA.

Kerres, M. (2013). Mediendidaktik: Konzeption und Entwicklung mediengestützter Lernangebote. In *Mediendidaktik*. Oldenbourg Wissenschaftsverlag. https://doi.org/10.1524/9783486736038

Kerres, M. (2018). Mediendidaktik: Konzeption und Entwicklung digitaler Lernangebote. In *Mediendidaktik*. De Gruyter Oldenbourg. https://doi.org/10.1515/9783110456837

Knaack, R., Wickert, J., Volz, D., Münchbach, N., Eich, W., Hug, P., & Hocker, T. (2019). Einsatz von" Virtual Reality" in der Ausbildung von Ingenieurinnen und Ingenieuren. *4. Symposium Zur Hochschullehre in Den MINT-Fächern, Nürnberg, 26.-27. September 2019*, 176–183.

Köhler, T., Münster, S., & Schlenker, L. (2013). Didaktik virtueller Realität: Ansätze für eine zielgruppengerechte Gestaltung im Kontext akademischer Bildung. *Hochschuldidaktik Im Zeichen von Heterogenität Und Vielfalt: Doppelfestschrift Für Peter Baumgartner Und Rolf Schulmeister*, 97–110.

Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: Immersion aids recall. *Virtual Reality*, *23*(1), 1–15. https://doi.org/10.1007/s10055-018-0346-3

Kröner, S., Christ, A., & Penthin, M. (2021). Stichwort: Digitalisierung in der kulturell-ästhetischen Bildung – eine konfigurierende Forschungssynthese. *Zeitschrift für Erziehungswissenschaft*, *24*(1), 9–39. https://doi.org/10.1007/s11618-021-00989-7

LaValle, S. M. (2016). *Virtual Reality*. http://lavalle.pl/vr/

LaViola, J. J., Kruijff, E., McMahan, R. P., Bowman, D., & Poupyrev, I. P. (2017). *3D User Interfaces: Theory and Practice*. Addison-Wesley. https://pub.h-brs.de/frontdoor/index/index/docId/3009

Le, D. T. G., & Nguyen, L. (2021). An efficient force-feedback hand exoskeleton for haptic applications. *International Journal of Intelligent Robotics and Applications*, *5*(3), 395–409. https://doi.org/10.1007/s41315-021-00197-w

Liu, D., Dede, C., Huang, R., & Richards, J. (2017). *Virtual, augmented, and mixed realities in education*. Springer Berlin Heidelberg.

Maas, M. J., & Hughes, J. M. (2020). Virtual, augmented and mixed reality in K–12 education: A review of the literature. *Technology, Pedagogy and Education*, *29*(2), 231–249. https://doi.org/10.1080/1475939X.2020.1737210

Martín-Gutiérrez, J., Mora, C. E., Añorbe-Díaz, B., & González-Marrero, A. (2017). Virtual Technologies Trends in Education. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(2), Article 2. https://doi.org/10.12973/eurasia.2017.00626a

Niedermeier, S., & Müller-Kreiner, C. (2019). VR/AR in der Lehre!? Eine Übersichtsstudie zu Zukunftsvisionen des digitalen Lernens aus der Sicht von Studierenden.

Pantelić, A., & Vukovac, D. P. (2017). The Development of Educational Augmented Reality Application: A Practical Approach. *ICERI2017 Proceedings*, 8745–8752. https://doi.org/10.21125/iceri.2017.2399

Pantelidis, V. S. (2009). Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. *Themes In Science and Technology Education*.

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785.

Pirker, J., Dengel, A., Holly, M., & Safikhani, S. (2020). Virtual reality in computer science education: A systematic review. *26th ACM Symposium on Virtual Reality Software and Technology*, 1–8.

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. https://doi.org/10.1016/j.compedu.2019.103778

Reinmann-Rothmeier, G., & Mandl, H. (1997). Lehren im Erwachsenenalter. Auffassungen vom Lehren und Lernen, Prinzipien und Methoden. *Psychologie Der Erwachsenenbildung*, *1*.

Reynard, R. (2017). *The Impact of Virtual Reality on Learning* -. Campus Technology. https://campustechnology.com/articles/2017/04/26/the-impact-of-virtual-reality-on-learning.aspx

Salzmann, C. (2007). Lehren und Lernen in außerschulischen Lernorten. *Handbuch Didaktik Des Sachunterrichts, Bad Heilbrunn*, 433–438.

Schüßler, I., & Thurnes, C. (2005). *Lernkulturen in der Weiterbildung*. wbv Media. https://doi.org/10.3278/42/0009w

Schwan, S., & Buder, J. (2006). *Virtuelle Realität und E-Learning*.

Shuell, T. J. (1986). *Cognitive Conceptions of Learning*. https://journals.sagepub.com/doi/10.3102/00346543056004411

Siebert, H. (1991). Lernwiderstände lerntheoretisch gesehen. *Literatur-Und Forschungsreport Weiterbildung*, *28*, 75–81.

Velev, D., & Zlateva, P. (2017). Virtual reality challenges in education and training. *International Journal of Learning and Teaching*, *3*(1), 33–37.

Villena Taranilla, R., Cózar-Gutiérrez, R., González-Calero, J. A., & López Cirugeda, I. (2022). Strolling through a city of the Roman Empire: An analysis of the potential of virtual reality to teach history in Primary Education. *Interactive Learning Environments*, *30*(4), 608–618. https://doi.org/10.1080/10494820.2019.1674886

Vogel, J. J., Greenwood-Ericksen, A., Cannon-Bowers, J., & Bowers, C. A. (2006). Using Virtual Reality with and without Gaming Attributes for Academic Achievement. *Journal of Research on Technology in Education*, *39*(1), 105–118. https://doi.org/10.1080/15391523.2006.10782475

Youngblut, C. (1998). Educational Uses of Virtual Reality Technology. *Institute for Defense Analyses*.

Zender, R., Sander, P., Weise, M., Mulders, M., Lucke, U., & Kerres, M. (2020). HandLeVR: Action-Oriented Learning in a VR Painting Simulator. In E. Popescu, T. Hao, T.-C. Hsu, H. Xie, M. Temperini, & W. Chen (Eds.), *Emerging Technologies for Education* (pp. 46–51). Springer International Publishing. https://doi.org/10.1007/978-3-030-38778-5_6

Zender, R., Weise, M., von der Heyde, M., & Söbke, H. (2018). Lehren und Lernen mit VR und AR–Was wird erwartet? Was funktioniert. *Proceedings Der Pre-Conference-Workshops Der*, *16*.