FINDINGS FROM A FIELD EXPERIMENT WITH A VR LEARNING UNIT

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ABSTRACT

The potential of using virtual reality in the school context is assessed heterogeneously from a scientific point of view. Especially the embedding in existing didactic approaches, the concrete design of the support system as well as the competence of the teachers are relevant. But it is undisputed that virtual reality opens up new possibilities to visit different out-of-school learning locations. However, it is not yet clear whether these opportunities have a significant impact on learning success. In this paper, three research questions about 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. The field experiment follows a classical A/B testing approach with pre- and post-tests. The results show that virtual reality can contribute to students' knowledge transfer. However, this contribution does not show a higher learning success compared to a classical didactic approach. Another result shows that combining virtual reality learning applications with a traditional teaching approach can be very successful. However, as long as virtual reality is a new experience for most students, the use of VR goggles leads to cognitive overload.

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 (Feierabend et al., 2019). 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 (Brade, 2015). 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) media can promote skills and constructivist learning beyond subject matter knowledge. 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 (Martin-Gutierrez 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 (Martin-Gutierrez 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: Can VR contribute to students' knowledge transfer?

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

RQ3: What criteria do you have to pay attention to 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 VR learning unit. The development and optimization of the artifact is oriented towards evolutionary prototyping (Bischofberger & Pomberger, 1992; Steinweg, 1995).

To determine the learning success of the VR learning unit, a qualitative field experiment with A/B testing (Döring & Bortz, 2016) will be conducted. The target group of the VR learning unit and the field experiment are middle school students of elementary and secondary schools. They are between nine and fifteen years old. The measurement of knowledge gain is implemented with the help of a pre- and post-survey. For this purpose, a questionnaire is designed, which is filled out by both groups before and after the completion of the learning unit.

3. STATE OF THE ART

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 (Kerres, 2013; Kerres & Witt, 2003). According to Schwan & Buder (2002) and Dede (2009), 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, 2002).
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 (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 (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).

Learning as a self-directed process

According to Arnold (2020), 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; Martin-Gutierrez et al., 2017; Schwan & Buder, 2002). 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 (Hellriegel & Čubela, 2018; Schwan & Buder, 2002). 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., 2018).

Learning as a productive and motivating process

Enthusiasm, motivation and emotions can be seen as important factors for learning success (Gieseke, 2003). 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, 2005), make complex issues tangible (Koehler et al., 2013), and can provide learners with freely selectable courses of action to ideally make self-directed decisions and explore virtual worlds (Martin-Gutierrez 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).

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 (2005) 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 (Koehler et al., 2013). Learners can view complex subject matter from a first-person perspective and make concrete connections in a physical presence (Martin-Gutierrez 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).

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), 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 (Martin-Gutierrez 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, 2005). 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. 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 (Zender et al., 2018).

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 & Plantak 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).

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 (augmented reality) (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 (Kerres, 2003).

One of the main challenges of VR learning applications is the currently scarce conceptual didactic basis (Zender et al., 2018). Many standard works on media didactics lack explicit treatment of VR (Kerres, 2018; Rey, 2010). 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 (Akçayır & Akçayır, 2017).

The use of VR requires media competence from teachers and learners (Zender et al., 2018). 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 (Akçayır & Akçayır, 2017). Teachers must also be able to operate the learning media and deal with error messages (Castellanos & Pérez Sancho, 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 (Keshavarz et al., 2014). Furthermore, immersive VR can create intense illusions, the physiological and psychological effects of which are difficult to assess (Zender et al., 2018).

5. FIELD EXPERIMENT AND RESULTS

The development and optimization of the artifact 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 https://osf.io/t4sxj/.

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, 8 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 (Brucker, Keller). 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 implementation 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 9, 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.

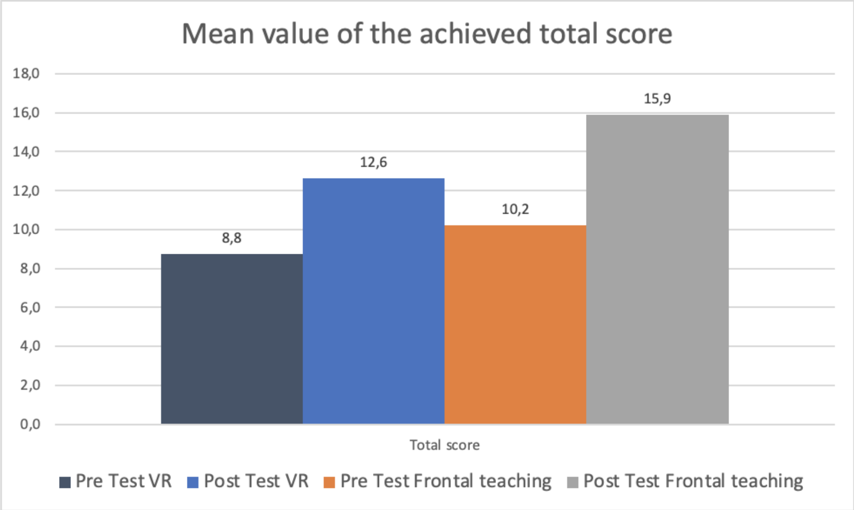

Figure 1. Average score for Realschule

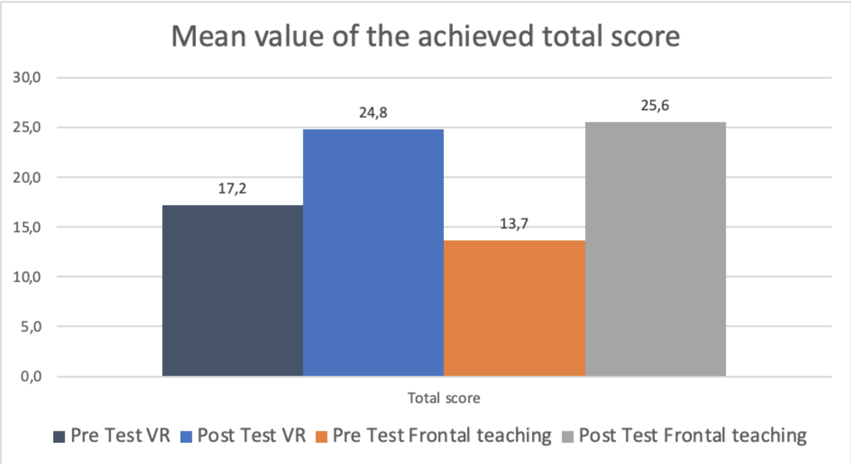

Figure 2. Average score for elementary school

6. CONCLUSION

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, the achieved total score and the percentage knowledge increase 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 the Realschule as well as of the Primarschule. Abstract questions about contents that are difficult to comprehend (questions 1-5), 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, as at the Realschule, 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 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.

The third research question can be answered with the findings from the literature review and the collected evidence from the observations of the qualitative field experiment. 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 in the two youngest participating subjects (nine years old). Going through the VR learning unit caused severe coordination problems for the 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. 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 knowledge. Further observations showed that learners with existing prior knowledge were better able to comprehend the size relationships and interrelationships of the solar system after completing the VR learning unit. The VR learning unit deepened the prior knowledge. VR technology can be used as a supplementary medium in the school day. Learners must be familiarized with the technology before conducting VR learning units and practice using it regularly to avoid health impairments and excessive cognitive load. The VR learning unit must build on existing knowledge and learners' attention must be directed to the essentials. Learners must be provided with guidance, both in and out of the VR environment. Outside of the learning unit, assistance can be provided by teachers or the fading in and out of information within the VR learning unit. 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.

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