Holly, M., Pirker, J., Resch, S., Brettschuh, S., & Gütl, C. (2021). Designing VR Experiences – Expectations for Teaching and Learning in VR. *Educational Technology & Society*, *24* (2), 107–119.

Designing VR Experiences – Expectations for Teaching and Learning in VR

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ABSTRACT: Skills in science, technology, engineering, and mathematics (STEM) are increasingly in demand. Theoretical knowledge and formulas alone are frequently not sufficient to understand complex phenomena. Simulations are a valuable tool to support the conceptual understanding by visualizing invisible processes. The constant interaction with the learning material is an essential factor when learning with simulations and virtual worlds. Virtual reality (VR) technologies enable interaction with the virtual environment with a high intensity of immersion. Maroon is a VR platform for teaching physics and has been in development for over five years. Previous results with Maroon have already demonstrated the potential of virtual reality for learners and teachers, but also highlighted a list of potential challenges in terms of VR experience design, usability, and pedagogical concepts. Over the past six months, we have conducted user studies with a total of 85 participants, both student teachers ($n = 26$) and pupils ($n = 59$) at high schools and teacher training institutions. In this paper, we want to facilitate the difficult task of designing educational VR platforms by describing the expectations of educators and pupils.

Keywords: STEM education, Virtual Reality, Interactive simulations, Immersive learning

1. Introduction

Innovative technologies and high-quality scientific research have a significant impact on our daily lives. Topics in the field of science, technology, engineering, and mathematics (STEM) are becoming more and more relevant and are a significant driver of innovation. Consequently, there is a growing demand for experts with experience, know-how, and skills in these fields (Zeidler, 2016). Olson and Riordan (2012) have already pointed out the need to increase the number of students with a degree in STEM disciplines. Lack of interest and enthusiasm are among the reasons for high failures in these fields. Students describe it as boring, complicated and uninteresting. It is not clear to many students why they must study natural sciences. It is therefore necessary to promote the interest and motivation of students in the STEM disciplines (Reeve, Jang, Carrell, Jeon, & Barch, 2004).

As Freedman (1996) shows, teaching science is a challenging task, especially in the field of physics. Traditional teaching methods present solutions and concepts, but they fail to teach how to solve problems. Hake (1998) confirms this observation by showing that students have difficulties understanding conceptual aspects while memorizing formulas. An old Chinese saying supports the concepts of learning through experience: “I hear, and I forget. I see and I remember. I do and I understand.” The integration of educational activities which involves learners in the learning process has shown to be a successful teaching method. Students learn by doing things and think about what they are doing (Freeman et al., 2014). Learning tools with interactive and engaging activities can help students to better understand such conceptual aspects. Sanders (2008) shows that in physics, the combination of hands-on experiments, interactive simulations and active participation are valuable tools that support learners during their educational process. Interactive simulations such as PhET (see https://phet.colorado.edu/) allow students to take the ownership of the learning experience and support their conceptual understanding by making connections to everyday life. They can be integrated into teacher demos, interactive discussions, classroom activities, labs and homework to support teachers in illustrating concepts (Moore, Chamberlain, Parson, & Perkins, 2014). This active learning concept can be extended by various modern technologies to meet the needs of a new generation of learners in a flexible and digital way. Simulations, visualizations, virtual and remote laboratories support students in self-directed, active, and group-based learning.

De Jong et al. (2013) showed that any lab form has its advantages for certain use cases. While real laboratories are more suitable for acquiring hands-on experience, virtual laboratories enable expandable experiments, multiple access and visual representation of unseen phenomena with minimal potential for the occurrence of dangerous situations. In virtual laboratories designed for active learning , learners become part of the simulated environment by interacting with the virtual world, which helps them to learn complex concepts. The combination of simulations and visualizations in a lab-like environment offers schools and universities a cost-effective way to provide learning experiences similar to those in real-world labs (Asıksoy & Islek, 2017). The use of immersive and interactive technologies such as virtual reality opens new possibilities for creating engaging learning experiences.

In previous works (Pirker et al., 2017a; Pirker et al., 2017b; Pirker, Lesjak, Parger, & Gütl, 2018) we introduced Maroon, an interactive physics laboratory and experiment environment designed to teach physics in a more engaging and immersive way. In small-scale studies we found that various VR technologies can be used to support and engage learners in understanding physics. Maroon supports immersive VR, where a stereoscopic head-mounted display (HMD) that is tracked by sensors is used. With the HMD and controllers it is possible to achieve spatial immersion and to conduct hands-on experiments. Additionally, Maroon can be used on a PC (desktop VR), where a three-dimensional world is simulated on-screen. In a recent study (Pirker et al., 2019a) we collected qualitative data from secondary school teachers to identify use cases, design goals and issues. In this paper we intend to extend our previous work (Pirker, Holly, & Gütl, 2020) to facilitate the difficult task of designing educational VR platforms by describing the challenges and the expectations of educators and pupils. The main research goals are defined as the following:

- Identification of educator and learner expectations for teaching and learning in VR.
- Providing a first guideline for the design of a VR learning environment for the classroom.
- Discussion of challenges and recommendations for the design and development of learning and teaching activities in VR.

Contribution: In this paper, we present a study with 26 student teachers and 59 pupils, discussing the room-scale VR version of the learning environment Maroon for physics education in classroom situations. The focus is on identifying and discussing expectations for teaching and learning in VR and challenges by combining the study results with a literature review.

The following section gives an overview of the background and the related work in the field of STEM education and of the challenges in designing educational VR platforms. In Section 3, we introduce the virtual physics laboratory Maroon and the conceptual design of the experiments and simulations. Section 4 describes the study design, and Section 5 presents the results. In Section 6, we discuss the challenges and recommendations based on the literature review and our findings. Section 7 closes with a discussion about implications, potential and gives some ideas for further studies.

2. Related work

STEM subjects have high drop-out and failure rates. This can be related to difficulties students have in understanding theoretical concepts (Olson & Riordan, 2012). Therefore, researchers such as Olson and Riordan (2012) or Dori, Hult, Breslow, and Belcher (2007) combined traditional classroom experiences with interactive and engaging digital learning experiences such as virtual simulations or animations to help students better understand the underlying concepts and phenomena. Conducting experiments in virtual or remote laboratories that would otherwise be dangerous, hard to conduct and/or too expensive is another way for effectively support learners (Corter et al., 2007). Wieman and Perkins (2005) showed that digital resources are a cost-effective, safe, and fast alternative to traditional learning methods and experiment setups. Furthermore, these digital resources have been shown to help users to achieve a better understanding.

VR tools can support the students in their learning process. Slavova and Mu (2018) showed that when using VR as a complementary tool to traditional learning methods, students showed higher performance in understanding and recognizing concepts. Furthermore, learners using VR technologies remain more motivated during their learning process (Liou & Chang, 2018). Bogusevschi, Muntean, and Muntean (2020) have published a study on the effect of a virtual 3D physics learning environment on 12-13-year old students that concluded that over 74% of the participants found the simulation helpful for gaining a better understanding.

Due to the decreasing prices of HMDs, we could observe that an increasing number of studies on the use of VR, especially for educational use, have been published. Furthermore, HMDs have become lighter and even wireless alternatives, such as the Oculus Quest, are now available, factors which are helping to increase their broad distribution and use. Due to the lower costs of HMDs, the increased research and the technical process, VR is becoming both more immersive and more widely available to a wider user base (Dempsey, 2016), making it easier to use VR learning experiences as an addition to the traditional classroom setups.

Nevertheless, researchers are still investigating the challenges that arise from the use of VR as a learning tool. Velev and Zlateva (2017) point out that a highly immersive experience must be created to achieve a high learning rate. According to Stark (1995) VR does not depend on highly realistic surroundings, as long as the virtual space offers enough cues for the perceptual system, immersion can be achieved. It is of greater importance when creating an immersive experience that the motion sickness is reduced to a minimum and the interface design of the VR simulation is appealing (Callaghan, Eguíluz, McLaughlin, & McShane, 2015). Especially in the field of physics, immersive learning experiences help to achieve a better understanding, particularly if the design places a special emphasis on interactivity (Pirker, Gütl, Belcher, & Bailey, 2013; Pirker, Berger, Guetl, Belcher, & Bailey, 2012). Abulrub, Attridge, and Williams (2011) confirm that for a high learning rate, the VR experience must be designed so that the user can actively interact with the virtual world.

Furthermore, not only the setup time of HMDs and virtual simulations for the use in real classrooms could become problematic, but also the time needed for students to become familiar with the new technology (Velev & Zlateva, 2017). They need a guided tutorial or someone to help them and guide them through their first experiences (Abdelaziz, Alaa El Din, & Senousy, 2014; Safikhani, Holly, & Pirker, 2020). De Jong and Van Joolingen (1998) describe that it has a positive influence on the learning effect when theoretical information is available during the simulation. Additionally, they explain that tasks help the users to focus on the desired outcome and guide them through the experience. Most teachers have limited time and classroom settings usually provide limited hardware resources, factors which reduce the time each of their students has in the virtual laboratory. Most VR learning experiences allow only limited personal interactions, which makes collaborative learning and teamwork difficult (Velev & Zlateva, 2017).

One of the most challenging, but also most promising parts of VR learning experiences is the optimization of the knowledge acquisition process. Mainly Callaghan, Eguíluz, McLaughlin, and McShane (2015), Velev and Zlateva (2017) and Liou and Chang (2018) discovered various guidelines for designing VR learning experiences. Creating a good virtual experience requires that users are not initially overwhelmend with the virutal world, which can be achieved by reducing dizziness and motion sickness. Furthermore, VR laboratories offer many possibilities that conventional ones cannot provide. For example, invisible phenomena can be visualized and made interactable and students can perform dangerous and expensive experiments. Students are offered a fully controllable and safe learning environment that reduces health risks, in case of performing dangerous experiments, and ensures that the same input will always lead to the same output. It also gives learners the possibility to apply their theoretical knowledge in practice, which motivates them and boosts their creativity. Given the large number of studies focusing on VR learning environments and laboratories, Ip and Li (2015) criticize that most of them failed to demonstrate an increase in long-term knowledge acquisition and that more long-term observations should be made.

3. Maroon – Virtual learning application

Maroon (see https://maroon.tugraz.at; to put someone ashore and abandon them on an island) is an interactive virtual physics laboratory that allows students to explore various experiments and phenomena in an immersive and engaging way. It is implemented in Unity (see https://unity.com) and supports different platforms with different levels of immersion such as virtual reality, mobile devices, or web-based applications. The learning activities and experiments are designed for active learning to involve students in the learning process. The main laboratory room (Figure 1) consists of different experiment stations and functions as a three-dimensional menu where the user can select one of the experiments by navigating to the specific station. Currently, the laboratory contains a whiteboard scene with different learning lessons, and eight experiments in the field of electromagnetism, electrostatics, oscillation, and waves (Pirker et al., 2019b). The experiments support several virtual learning experiences with different forms of engagement and immersion through diverse activities and interactions. In the following subsections the application concepts of Maroon VR and the different experiment setups are presented.

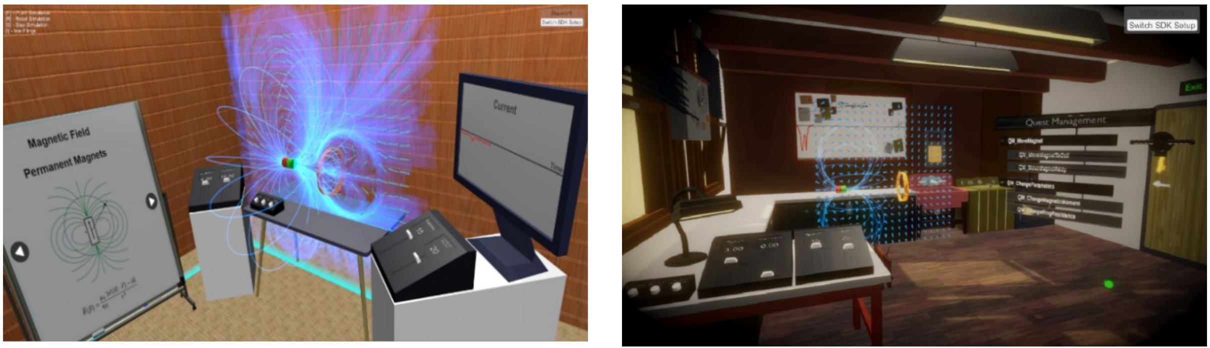
Figure 1. Overview of Maroon's laboratory with different learning stations

3.1. Maroon VR

The VR version of Maroon extends the core functionalities of Maroon with room-scale VR support for the HTC Vive (see https://www.vive.com) and the Oculus Rift (see https://www.oculus.com/rift). This version of Maroon offers a virtual reality experience with a high degree of immersion and focus on the learning content. Users can walk freely in the classroom within a predefined play area, allowing natural movement within the virtual environment. Due to real-world restrictions and the limitation of the tracking area, users need to become familiar with a different form of movement to cover greater distances in the virtual world. In VR applications, teleportation has become a standard and allows the user to move to a certain position while minimizing the feeling of motion sickness. For teleportation, the user can press a button on the controller to activate a colored arc, by moving the controller the user can point to the desired destination. After releasing the button, the user is placed in that position. Teleport markers in front of each experiment station help to navigate to a specific experiment by capturing the teleport beam. Each experiment or activity can be started from an entry-point that acts as a portal into the simulation room. Each experiment has a customized user interface and offers various virtual control elements to control specific experiment parameters and visualizations.

3.2. Experiment setups in VR

Maroon VR supports two different types of experiment setups each with an individual design. The first experiment setup contains only the elements necessary for the simulation (see Figure 2a). The experiment is placed in the middle of a simple and compact room and can be controlled via virtual control panels on the right and left side. This allows the user to observe the experiment results while setting the experiment parameters. To keep the interaction as simple as possible, all elements are arranged in such a way that they are accessible without use of teleporting. In contrast, the second setup contains additional gamified elements in a retro-futuristic laboratory room with a simplified design to improve student's engagement and motivation (see Figure 2b). The predefined quest list gives clear instructions by displaying different tasks, the progress, and additional information about the simulation.



(a) (b)

Figure 2. Different design setups in VR: a) simple experiment room with virtual control elements and b) retro-futuristic laboratory room with quest management system

3.3. Experiments and simulations

In this section the two interactive experiments Faraday's Law and Huygens's Principle are presented, which were used to evaluate the room-scale VR version of Maroon. The goal of these simulations is to simulate and visualize the concept of induction and diffraction. Each of them implements the general physical phenomenon and extends it with an appropriate user interface. The Faraday's Law Experiment shows the principle of induction when interacting with a permanent magnet and a conductive non-magnetic ring. Whenever the user moves the magnet, it causes a change in the magnetic flux and induces an electric current that generates another magnetic field. Through different visualizations the invisible magnetic field becomes visible and helps the user to better understand the underlying concepts. The virtual controls allow the user to influence the result of the experiment by changing the parameters of the magnet and the coil. The special feature of this experiment is the haptic feedback from the controllers, which allows the user to feel the acting forces. The controller vibrates as soon as a physical force acts on the magnet, where low vibration means a weak force, and high vibration means a heavy force. This allows users to have a real feeling of the acting forces. The Huygens's Principle Experiment uses water waves in a basin to demonstrate the physical concept of diffraction. It is a phenomenon that occurs when a wave hits an obstacle or a slit. To show the effect of diffraction, a slit plate is placed into the basin. When a wave hits this plate, the points on the wave act as a new source of secondary waves that propagate. This results in an interference pattern behind the plate. To obtain different interference patterns, the user can replace the plate with three types of slit plates. The experiment is influenced by the user by grabbing and moving the plates and changing physical parameters such as frequency, amplitude, wavelength, or the propagation mode. To make the wave peaks and wave trough more visible, the wave color can be changed using a color wheel.

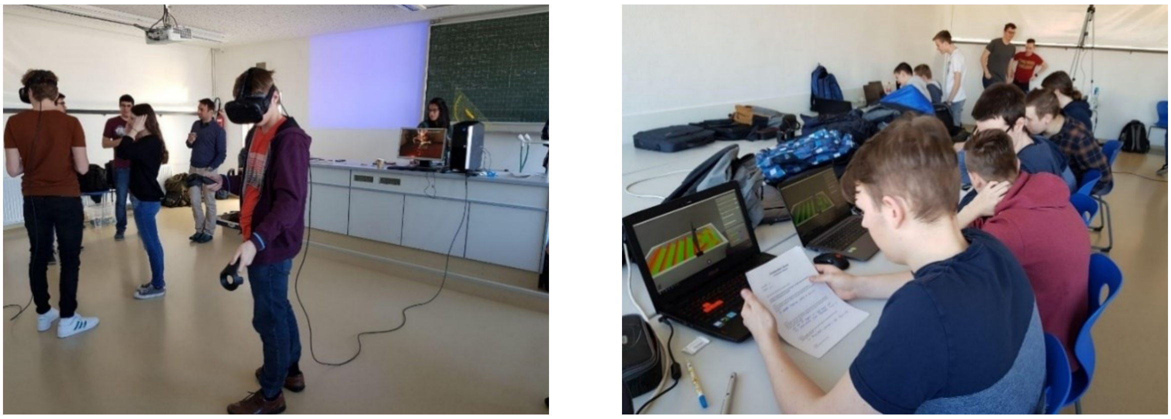
4. Evaluation

In previous studies, we focused on different learning experiences with room-scale VR, mobile VR, and traditional screen-based technologies as well as on engagement, usability, and user experience with room-scale VR as the most engaging and most immersive form. However, we also found that teachers and students have very different opinions and expectations about experience design in VR. Therefore, in this paper, we focus in this paper on identifying teacher and pupil expectations for teaching and learning in VR. Since there are known issues convincing experienced teachers to try new things in educational technology, we conducted a user study with 26 student teachers and 59 pupils, which are open for new technologies. The study was organized in cooperation with two local schools and two universities with a focus on the following:

- Experience and engagement,
- Usability,
- Learning value from learner's perspective,
- Learning value from teacher's perspective.

4.1. Setup

We used two portable setups, including a gaming notebook, an HTC Vive HMD, two controllers, two lighthouses, and two tripods for the lighthouses. The two setups were placed in a single classroom with a minimum size of 2m x 2m for each VR station. All participants were in the same classroom and worked in pairs. Half of the participants tested the simple design of the experimental room, and the other half tested the retro-futuristic laboratory room. While the persons who tested the experiments in VR were given instructions from their partners outside (Figure 3a), the others tried the same experiments in the desktop version (Figure 3b). After 20 minutes, the groups were swapped, so that the participants using the VR version were now using the PC version and vice versa. To get a real classroom situation the setup was conducted within the context of a physics class and in a university classroom where the student teachers were role-playing as pupils. During the tests participants were not wearing earphones so we could talk to them and guide them through the experiments.



(a) (b)

Figure 3. Classroom setup: a) VR workstation and b) desktop workstation

4.2. Material and procedure

For this study, we worked with two high schools and two universities to test Maroon from the perspective of students and prospective teachers. At the beginning of each test run the participants were asked to fill out a pre-questionnaire to obtain information about their ages, gender, experience with games, VR platforms, and e-learning tools. They were then given a short introduction how to work and interact with the environment. We introduced them to the controls and gave them instructions for the different tasks to be completed during the test run.

Pupils and student teachers were asked to perform the following tasks:

- Introductory session: Have a look at the lab environment and get a first impression.
- Go to the Faradays' Law experiment and start the simulation by moving the magnet. Try to identify the relationship between the electrical current and the acting force. Find out how the parameters of the magnet and the coil affect the experiment outcome.
- Go to the Huygens' Principle experiment and start the simulation. Try to understand the concept of diffraction and describe the interference pattern behind the slit plate.
- Take time to try other experiments (optional).

We provided an additional exercise sheet for the pupils in which they could work on different questions about the experiments. After conducting the experiments, the participants were asked to fill out a post-questionnaire in which they had to answer open-ended questions about their overall experience; 22 questions on a Likert scale between 1 (fully disagree) and 5 (fully agree) about their sentiment towards the physics lab, and 10 questions regarding usability. We used the System Usability Scale (SUS) (Brooke, 1996) to measure the system usability and the Computer Emotion Scale (Kay & Loverock, 2008) to assess users' experiences of interacting and learning with the virtual environment. To gain a deeper understanding of the user experience and use cases, pupils and student teachers were interviewed about the experiments and application scenarios in school classes. Student teachers were also asked about pedagogical models and cooperative scenarios.

4.3. Participants

In total 40 high school pupils, 19 pupils from an engineering secondary school (51 male, 8 female) and 26 student teachers (15 male, 11 female) took part in the user study. All 26 student teachers were attending the teacher education program for physics. The pupils were aged 13 to 19 (*AVG* = 14.41, *SD* = 1.87) and the student teachers from 21 to 31 (*AVG* = 23.69, *SD* = 2.65). 14 pupils and 11 student teachers had a visual impairment (including people wearing glasses).

We asked each of them to rate their experience with computers, video games and VR on a Likert scale from 1 (low) to 5 (high). Most pupils rated themselves as experienced with computers (*AVG* = 3.22, *SD* = 0.91) and video games (*AVG* = 3.59, *SD* = 1.16). Student teachers stated that they were also experienced in using computers (*AVG* = 3.12, *SD* = 0.91) but rated their experience with video games lower (*AVG* = 2.54, *SD* = 1.65). Pupils and student teachers indicated that they often play video games (pupils: *AVG* = 2.68, *SD* = 1.41; teachers: *AVG* = 2.27, *SD* = 1.46). 52 of the pupils and 16 of the student teachers liked playing video games but had little experience with VR (pupils: *AVG* = 1.69, *SD* = 0.93; teachers: *AVG* = 1.50, *SD* = 0.86). 52 pupils and 19 student teachers had heard about VR devices previously, but only 22 pupils and 7 student teachers had tried one. 45 pupils and 20 student teachers have already used an e-learning tool. Both pupils and student teachers consider the use of virtual reality in physics lessons to be a good idea.

5. Results

In this section, we describe the results obtained from the open-ended answers and the answers based on a Likert scale. Since the learning outcome depends on the user experience and the acceptance of the system, we focus on usability, engagement, immersion, and the learning experience as well as on application scenarios and pedagogical models.

5.1. Usability and user experience

Most participants were able to handle the VR controllers without any problems. Only a few of them had some initial problems when they tried to move in the virtual world or wanted to interact. They teleported themselves against walls or used the wrong button for interaction. By contrast, all participants were able to interact with the PC version without additional instructions. The users described the desktop application as more familiar but would prefer the interaction in VR as it is more realistic and natural. We used the Computer Emotion Scale to evaluate the emotions anger, anxiety, happiness, and sadness when learning with the VR environment. As shown in Table 1, pupils and student teachers rated the emotion happiness (e.g., satisfied, excited, curious) as high and the emotions of sadness, anger, and anxiety as very low. In total 44 pupils and 23 student teachers have completed the SUS questionnaire. It shows the degree of usability from 0 (poor) to 100 (excellent) and was rated with 76.5 by pupils and with 73.5 by student teachers. The resulting scores indicate an above average usability compared to other VR learning tools. When we asked participants whether they felt nauseous or dizzy while using VR, only two pupils and one student teacher reported cyber sickness.

Table 1. Results of the 12-item Computer Emotion Scale on a Likert Scale between 0 (never) and 3 (always)

	Pupils		Student Teachers	
	AVG	*SD*	*AVG*	*SD*
Satisfied	2.63	0.48	2.58	0.69
Excited	2.78	0.41	2.73	0.44
Curious	2.73	0.48	2.73	0.44
Happy	2.46	0.56	2.42	0.74
Depressed	0.15	0.48	0.04	0.19
Discouraged	0.36	0.73	0.04	0.19
Scared	0.22	0.49	0.08	0.27
Insecure	0.54	0.62	0.69	0.72
Helpless	0.41	0.49	0.46	0.57
Nervous	0.51	0.74	0.38	0.56
Frustrated	0.03	0.18	0.08	0.27
Angry	0.05	0.39	0.04	0.19

5.2. Immersion and engagement

Pupils rated the immersion of the experience on a Likert scale from 1 (not immersive at all) to 10 (fully immersive) as an average of 9.00 (*SD* = 0.98). Some pupils mentioned that learning with Maroon was easier and more engaging than traditional learning methods. Only two pupils experienced dizziness, which could hinder a convincing user experience.

Prospective student teachers rated the immersion of the experience on the Likert scale from 1 to 10 slightly lower than the pupils with an average of 8.50 (*SD* = 1.24). Among other things, it was noted that Maroon VR has a high degree of interaction that allows the inclusion of multiple senses. Furthermore, some of the student teachers mentioned the feeling of forgetting about being in a virtual world after spending some time within Maroon, which was induced by the high degree of interaction.

5.3. Learning value from the learner's perspective

To evaluate the learning experience, pupils were asked to rate their learning experience on a Likert scale between 1 (not agree) and 5 (fully agree). Table 2 gives an overview of the pupils' results with a focus on learning experiences. The pupils indicated that the experience was more engaging (*AVG* = 4.17, *SD* = 0.91) and fun (*AVG* = 4.68, *SD* = 0.63). In general, learners found that the lab made the content more interesting and easier to understand. Most of them said they would like to learn with Maroon (*AVG* = 4.39, *SD* = 0.89).

They also reported that they liked the immersive laboratory and outlined that concepts are easier to understand using three-dimensional visualizations and interactions than with traditional methods. Being able to see field-lines that are usually not visible contributed to this. They also mentioned that compared to real life experiments it was easier to conduct the experiments in VR and that Maroon was a fun experience and was a welcome relaxation from their typical school routine. Suggestions for improvements made the experiments look even more realistic, further improving the visualizations. A larger collection of experiments was also mentioned to improve Maroon.

5.4. Learning value from the teacher's perspective

Besides pupils, student teachers were also asked to rate the learning experience with Maroon on a Likert scale between 1 (not agree) and 5 (fully agree). Most student teachers mentioned that the VR setup is a good supplement to regular learning (*AVG* = 4.15, *SD* = 1.08). They also reported that Maroon makes the learning content more interesting (*AVG* = 3.88, *SD* = 1.18) and easier to understand (*AVG* = 3.65, *SD* = 1.13). In general, student teachers found that learning with Maroon was more motivating than ordinary exercises and more fun, as can also be seen from Table 2.

The student teachers reported that VR can be a good way to extend the variation of teaching methods in the classroom. The fact that Maroon appeals to multiple senses makes the system attractive for several types of learners, while the novelty of the technology is an attractive way to motivate students who normally show little interest in a subject. It was also mentioned that virtual experiments are valuable when the real experiment is expensive or dangerous, since students can carry these out with no health risks. Also mentioned was the possibility of visualizing unseen phenomena, learning in a playful way and the ability to change the experiments very quickly. Some student teachers criticized Maroon as being too close to regular games in its current state, and this makes it more difficult to keep students focused. To allow students to use it without close monitoring and guidance, and to prevent students from being distracted, the system should include detailed tasks with clear instructions. It was also found that obtaining enough VR headsets for all students is currently too costly and for this reason would be best to use the technology in the form of projects days. The setup time for the system can be regarded as reasonable in the context of such a project day.

In addition, student teachers recommended the use of videos in Maroon to provide additional support in the form of introductory film material that revisits the learning topics discussed, or videos showing the experiment and additional information to support the process of learning while experimenting in VR.

Table 2. Learning Experience rated by pupils and student teachers on a Likert Scale between 1 (not agree) and 5 (fully agree)

	Pupils		Student Teachers	
	AVG	*SD*	*AVG*	*SD*
I would like to learn with Maroon.	4.39	0.89	3.54	1.27
It is a good idea to use Maroon for learning.	4.51	0.86	3.92	0.98
Maroon is a good supplement to regular learning.	4.56	0.79	4.15	1.08
I learned something with Maroon.	4.08	0.92	2.69	1.23
Maroon makes the content more interesting.	4.63	0.64	3.88	1.18
Maroon makes the content easier to understand.	4.27	0.89	3.65	1.13
Maroon makes learning more engaging.	4.17	0.91	3.19	0.85
Maroon makes learning more fun.	4.68	0.63	4.08	1.09
Maroon makes learning more interesting.	4.46	0.73	3.96	1.08
The experience with Maroon inspired me to learn more about physics.	3.49	1.22	3.12	1.21
Learning with Maroon was more motivating than ordinary exercises.	4.51	0.70	4.23	0.95
It makes course content more interesting to learn about.	4.44	0.77	3.62	1.10
I would rather like to learn Physics with Maroon than with traditional	4.14	0.96	2.81	1.27

methods.				
I find regular physics classes boring.	3.19	1.25	1.54	0.58
Seeing the simulations with the VR glasses was engaging.	4.17	0.81	3.81	0.98
Seeing the simulations with the VR glasses was interesting.	4.42	0.65	4.54	0.58
Seeing the simulations with the VR glasses was more engaging than without.	4.37	0.87	3.96	1.04
I would rather use Maroon on my phone (+ VR glasses).	3.34	1.36	2.85	1.22
I would rather use Maroon on my own PC.	3.81	1.07	3.12	1.24
I would like to learn with Maroon in the classroom.	4.41	0.87	3.77	0.99
I would buy the VR glasses and download Maroon at home.	3.81	1.12	3.04	1.46
It was interesting to use Maroon.	4.81	0.43	4.73	0.53

5.5. Use cases and pedagogical models

The perspectives of pupils and teachers are often quite different. To consider their ideas and suggestions on how to use VR in schools and what can be learned in VR into consideration, we asked the pupils and student teachers in open questions to describe their ideas and scenarios. Based on these answers, we provide a list of use cases and subjects that can be applied in schools.

5.5.1. How to use VR in schools

To identify different use cases, we asked pupils (P) and prospective student teachers (T) how they would use VR in school. Student teachers were also asked to give collaborative scenarios as well as pedagogical models.

The following use cases were mentioned:

- *Dedicated VR room (P, T)* – Pupils mentioned that they would prefer a dedicated classroom for learning with VR. This includes learning as an integral part of classroom lessons as well as after-school (extracurricular) activities to repeat and review the learned materials. The student teachers also suggested a dedicated room with pre-installed VR setups to save time.
- *Mobile VR experience (P, T)* – Due to the financial constraints, pupils and student teachers mentioned the usage of smartphones in combination with a mobile VR headset. That allows pupils to run experiments on their devices at school and at home. But are limited in their use due to the processing power of these devices.
- *Weekly classes (P, T)* – Some pupils suggested using VR on a weekly basis to supplement the learning material with simulations and visualizations. Student teachers also mentioned the potential of regular VR sessions in classes to increase the learning outcomes of pupils.
- *Optional Subject (P)* – Pupils also recommended an optional subject or an afternoon class where they can use VR for learning and increasing their skills.
- *Project/Group Work (T)* – Several student teachers reported the potential of blocked VR classes in the form of project days during which pupils can work in groups on different experiments.
- *Autonomous Learning (T)* – The student teachers mentioned that VR as an effective educational method, could be a valuable tool to support students in autonomous learning. They also mentioned that using worksheets might be useful to give pupils clear instructions and help them to focus on the experiment.
- *Collaborative Learning (T)* - Since pupils benefit from each other's resources and skills when learning together, student teachers suggested working in groups, where one pupil performs the experiment and the others give hints and take notes.

5.5.2. Teaching subjects

To identify additional subjects and experiments, we asked pupils and student teachers about phenomena they would like to see, learn, or teach in VR.

The following subjects were mentioned:

- Astronomy
- Physics
- Chemistry
- Biology

- History
- Engineering

While pupils were interested in different STEM subjects, the student teachers were mainly interested in experiments in their own field – physics. All of them also highlighted that VR would be an opportunity for performing expensive and dangerous experiments within class and for visualizing and experimenting with unseen phenomena.

6. Discussion

In this study, we examined the challenges and recommendations for learning and teaching in VR, with an exemplary focus on the physics domain. In previous studies (Pirker et al., 2017a; Pirker, Lesjak, Parger, & Gütl, 2018), we have evaluated different VR experiences versus a classic desktop experience with a small group of students and teachers. We showed the potential of VR in the field of STEM and discussed the advantages and disadvantages. In this paper, we aim to facilitate the challenging task of designing VR learning platforms by describing the challenges and giving some recommendations to overcome these challenges.

6.1. Challenges and recommendations

Summarizing the findings of our research and study, we concluded that we can distinguish between the following main challenge categories: (1) immersion, (2) costs, (3), time restrictions, (4) knowledge gaining process.

To achieve an increased learning effect, it is crucial to offer a highly immersive experience, since then the user becomes part of the virtual world. Moreover, motion sickness should be restricted to a minimum. We recommend using HMDs combined with motion tracking and input devices that enable the interaction with the virtual world, as this already ensures a high level of immersion. Furthermore, the user interface should be tailored to the VR world, meaning that we create an appealing interface design and give the learners the possibility to interact directly with their learning content. As a result, users show more motivation for the learning content and simulations as we enable them to learn and explore the phenomena in a playful way (Velev & Zlateva, 2017; Callaghan, Eguíluz, McLaughlin, & McShane, 2015). We observed that students could ask questions regarding controls and experiment specifics, because the headsets were not equipped with earphones. This was especially helpful for first-time VR users, because they could show where a problem was in VR and we could see what they were trying to accomplish on-screen and point them in the right direction.

Another factor for using VR experiences complementary to the traditional classroom learning methods are the included costs. VR equipment prices already decreased in the previous years and HMDs are now available to a broader user base. Nevertheless, it is still a significant factor for most schools as they cannot afford to buy many HMDs and equip whole classes (Abulrub, Attridge, & Williams, 2011). We thus recommend using VR setups within project days, so that less VR equipment will be needed. Using VR laboratories instead of traditional ones reduces the costs of laboratory equipment and gives learners the possibility to perform even expensive experiments within the virtual world as many times as they want. Such an approach presents itself as a possible solution until mobile VR headsets can provide a similar degree of immersion and computing capabilities.

When using VR, an introduction of some kind is generally required to familiarize the user with the HMDs and controls. We must consider the training time for users (Velev & Zlateva, 2017). This can be optimized by using guided tutorials to explain how to use the controls (Abdelaziz, Alaa El Din, & Senousy, 2014), not to mention that with tutorials teachers do not need to guide each student personally and hence more time is saved. In addition, the setup time factor is significant if the VR equipment is to be used during traditional lessons. Hence, we recommend using the virtual laboratories within project days or coordinate with other classes, so that the equipment is in use throughout the whole day. In consequence the VR laboratory offers the possibility to change experiment settings or reset the simulation with a few commands. In addition, there is no need to prepare experiments in the real world, this is especially useful when having very time-consuming experiments.

To create a successful VR learning experience the knowledge gaining process should be optimized. Crucial for the success is that users should not be overwhelmed when first entering the virtual world (Callaghan, Eguíluz, McLaughlin, & McShane, 2015). Furthermore, it is important that the students know what the goal of the simulation is and that they do not feel lost in the simulation. During the tests, we noticed that already having background knowledge is a significant advantage for performing simulations. As Mayer's cognitive theory of multimedia states, learners receive information via two separate channels (visual and auditory) with limited capacity. Learners must select and organize the relevant information and integrate it based upon prior knowledge (Mayer, 2002). We found that a predefined quest list with clear task instructions in combination with worksheets can help students to stay focused and motivated. Moreover, with the use of VR we encourage the motivation of learners in a playful way while keeping them safe during the performance of dangerous experiments (Callaghan, Eguíluz, McLaughlin, & McShane, 2015). Through the use of VR we can provide users with the possibility for visualizing invisible phenomena, which proved to make the learning content more readily comprehensible for students (Slavova & Mu, 2018). The greatest advantage, however, is that learners can explore and interact with the simulations at their own pace and this motivates them, encourages their creativity and lets them utilize their theoretical knowledge.

6.2. Limitations

Due to the classroom setup in schools, the number of participants and the time constraints, an A/B split user study was not feasible. We therefore decided to set up the study as a workshop where participants tested the VR environment in a classroom situation. The different room layouts, light conditions and the shape of play areas had a marginal influence on the tracking accuracy, which caused slightly different experiences. While some pupils had experience in programming, VR, and video games, others had not been much involved in computer games, VR, and programming during their curriculum. The learning effects were determined by self-evaluation and do not indicate long-term effects. Since not all participants (15 pupils and 3 student teachers) completed the questionnaire, some data sets could not be included in the evaluation.

7. Conclusion

In conclusion, VR can offer an exciting and engaging ways to learn and teach. But there are still challenges that need to be overcome to make it feasible for schools. We wish to offer some recommendations on how to create an engaging VR learning experience, from which both students and teachers will benefit. Our core findings were that an immersive experience motivates students and encourages them to learn more. Moreover, time and costs are still crucial factors whether the VR laboratory will be included into school routines or not. Additionally, VR offers many possibilities and improvements for the knowledge gaining process, such as enabling the performance of dangerous experiments in a safe way or visualizing invisible processes.

Although participants rated the interaction with the laboratory as good, there is still potential for improvement, especially in the design and usability. Both pupils and student teachers requested a more accessible method for easier classroom integration. Future research should consider the potential of mobile VR devices such as smartphones or standalone devices and explore how we can integrate them into classrooms. For future work, it would be useful to port the current framework to mobile devices and explore how we can integrate these in classrooms. An important step would be to discuss the current results with experienced teachers and to obtain their feedback on the identified challenges and recommendations. Future studies could then investigate the different use cases to develop a pedagogical model for schools. In future the effect of not wearing earphones and of receiving tips, breaks and immersion could be investigated, or also if it could be a useful setup to have one student performing an experiment while one or more peers give hints on how to complete the tasks involved.

Acknowledgement

At this point, we would like to thank all participants of this study and all those people who are and were involved in the development process. This work was partly funded by the Ministry of Education, Science and Research of Austria.

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