Room Scale Virtual Reality Physics Education: Use Cases for the Classroom

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***Abstract*—Interactive and digital learning experiences are becoming increasingly important and used to improve various learning scenarios. In physics education, the use of digital simulations or virtual laboratories to support the learners' understanding is already part of most classrooms. Virtual reality experiences can be used to create even more exciting, engaging, and realistic learning setups to conduct experiments and work with simulations. A range of studies has shown a positive effect of virtual reality experiences for learning. In this paper, we explore the potential of physics education in virtual reality in school-based classroom scenarios. We present a study with 147 high school students from four different schools, to evaluate the potential of room-scale VR learning setups in classroom learning with a focus on engagement and learning experience and focus on dandifying potential use cases for learning experiences in schools from the students' perspective. In this study, we found that students described the experiences as highly engaging and a valuable tool to increase motivation in classrooms. They would rather use VR for learning in the classroom than at home. They prefer a PC-based VR setup over a mobile phone setup. Four main identified use cases for using VR in classrooms from the students' perspective are evaluated and discussed.**

***Index Terms*—Virtual Reality, Learning, Education, E-Learning**

I. Introduction

Pupils often describe STEM (Science, Technology, Engineering, and Mathematics) subjects as boring, complicated, and not interesting. As a result, failure and dropout rates are very high [1]. STEM fields require learners to understand concepts and underlying phenomena instead of memorizing single elements. Especially in physics education, the use of hands-on experiments, the interaction with simulations, and engaging learners through peer interactions have been shown as valuable tools to help learners [2]. Interactive engagement is a pedagogical concept to encourage learners to interact with the content more experimentally. This helps them to understand the underlying scientific concepts and phenomena [3], [4]. Digital tools such as simulations and remote and digital laboratories have been shown as valuable tools to support digital physics education. Real experiment setups are often expensive, complex to set up, and hard to repeat fast and efficiently. In contrast, digital tools support the simulation of hands-on experiments, allow students to repeat experiments easily and perform experiments that are often hard to try out in real life. Additionally, digital learning environments provide flexible and engaging forms of learning.

Especially the use of immersive and interactive solutions such as Virtual Reality (VR) technologies have been shown as an important potential next step to enhance learning experiences in schools. In previous work ([5]–[7]), we have presented Maroon, a virtual learning environment, which can be used with VR Head-Mounted Displays (HMDs) to learn physics in a more interactive, engaging, and immersive way. In previous small-scale studies, we presented and compared the different versions of VR technologies to use Maroon. We compared mobile VR versions with room-scale versions and found that this form of learning can be used to engage learners and that room-scale VR versions are described as more immersive and are better suitable for hands-on experiment setups. In a recent study, we focused on collecting qualitative data from high school teachers [8] to identify use cases, issues, and design goals. In this paper, we want to shed light on the VR learning experience of high school students in classroom settings to identify advantages, issues, and use cases from the learners' perspective. We present a first study with 147 high school students aged between 14 and 20 to learn more about the learning experience and engagement of students in classroom environments. While previous work has highlighted the point of view of the educators and teachers [8]–[10], in this study, we want to describe use cases identified and identified when talking with 147 high school students.

Contribution: In this paper, we present a study with 147 high school pupils, discussing the virtual reality learning environment *Maroon* for physics education in classroom scenarios. The focus is on identifying and discussing potential use cases of VR experience in school together with the main target group: the students.

II. Related Work

Especially for STEM education, interactive and engaging learning experiences have proven to be crucial tools to support

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learners and help them to understand phenomena and concepts [1]. For physics education, the use of simulations, animations, and digital interactive experiments has been used since many years as supplementary teaching material also in classroom settings to help learners to understand the underlying concepts of theoretical formulas and phenomena [11]. Also, the use of virtual and remote laboratories has been shown to support learners by providing them a digital environment to conduct experiments, which can be in real life too expensive, dangerous, or complicated [12]. It has been demonstrated that digital tools are a valuable resource to support the students' understanding, and that they are a cost-effective, safe, and fast alternative to traditional desktop experiments setups [13].

Especially virtual reality technologies have been shown as valuable tools to enable engaging and immersive laboratory learning setups. Early applications of virtual reality learning environments have already shown the potential of using these technologies to support the learner in understanding phenomena and engaging them while learning. Virtual reality has been shown as particularly successful when traditional lectures were inappropriate or difficult to explain the learning content [14]. Also, using virtual reality technologies to support physics education has been introduced very early and has been identified as a promising tool able to change the future of learning [15].

Since the introduction of low-cost and lightweight HMDs supporting virtual reality experiences, increasingly more researchers have looked into the effects of engaging students with the use of virtual reality experiences. In a study of 2020, the authors showed the potential from the users point of view and discussed the user experience of 12-13 year old children using a 3D virtual learning environment to learn physics [16]. As virtual reality has become more affordable, more immersive, and is now more and more available for a broader user base [17], we can think of new ways of introducing this technology in every day's classroom settings.

While many studies show the positive effect of VR on learning, engagement, and the user experience, and also the hardware is now in an affordable prize-range, it is crucial to understand better potential practicable use cases for learning with VR in schools.

III. Maroon - Virtual Learning Application

Maroon[1] is a three-dimensional learning application, developed in Unity[2] and designed similar to a first-person game. It is designed as a learning management system (LMS) and illustrated as a virtual laboratory environment with different experiment stations. The stations show representations of the learning content or experiments. As soon as a user (first-person view) approaches such a station, he or she gets teleported to a different scene, which allows the interaction with the learning experience. Maroon can be built to different operating systems and support different technologies such as virtual reality devices, mobile technologies, or web-based applications with different levels of engagement and immersion. Implementation details, as well as the evaluation of the different versions, can be found in [5]–[7].

In these studies, we found that room-scale VR experiences were described as most engaging and most immersive when compared to mobile VR setups or setups using a traditional PC. However, from a pedagogical point of view, it was also found that a room-scale setup will pose the biggest challenge for classroom setups and mobile VR solutions might be a better fit for such learning scenarios. Therefore, further studies have been designed and compiled to evaluate and define potential learning scenarios for room-scale VR setups, which are more suitable for the classroom. In a more recent previous study, we focused on identifying use cases, issues, and advantages from the teacher's perspective (see [8]). We found that the experiences of learners and educators highly differ.

As a result, in this paper, we want to focus on evaluating the room-scale virtual reality version of Maroon in classroom settings with the learners; in our case high school students. The goal is to evaluate and discuss potential learning scenarios with a room-scale virtual reality experience in school settings from the students' perspective and find out more about requirements, the potential, and challenges when bringing a VR experience to the classroom. For the evaluation described in this paper, we present a study focusing on the experience with the VR interaction design, the central laboratory room, and two interactive physics experiments explaining Faraday's Law and Huygens' Principle.

Experiments: To visualize *Faraday's Law*, we designed a virtual experiment where a magnet and a non-magnetic conducting ring are aligned on a horizontal axis. Users can interact with the magnet by grabbing it with the controller and moving it along the axis. As soon the magnet is moved through the ring, the current is induced. Information about the current is illustrated on a monitor. Users can also feel the acting force through haptic feedback in the controller. Elements such as the coil's mass and the resistance and the magnet's dipole moment can be changed on a panel to the user's right. To visualize and teach about *Huygens' Principle* (diffraction), we designed a virtual experiment setup with a basin filled with water in the middle of the room. In this basin, users can interact with a slit plate, move it from left to right, and observe the interference pattern generated by diffraction. Different forms of interactions are integrated. Users can grab the plate with the controller and move it. They can also change the length, frequency, and the color of the waves, as well as the propagation model.

IV. Evaluation

We performed a user study with 147 students using Maroon in four Austrian schools. The goal of the study was to identify the potential of room-scale VR setups in classrooms with a focus on the (1) overall experience and the students' engagement, (2) the usability, (3) the learning value, and (4) discuss use cases from the students' perspective.

[1]https://maroon.tugraz.at/

[2]https://unity3d.com/

A. Setup

The room-scale setup is designed to be portable. We use a Laptop, an HTC Vive[3] including the two lighthouses and the two controllers, and two tripods for the lighthouses. The setup area needs to be at least 2m x 2m. The setup time is about 20 minutes. For the evaluation, in each classroom, we set up two HTC Vive room-scale experiences. Only lighthouses were used to capture both HMDs. Per classroom, two students were able to conduct experiments at the same time, while the other students would observe and watch others interacting with the simulations. We did not use additional headphones, so students did not hear any sounds or audio so that we can talk to them during the experiments.

B. Material and Procedure

In previous studies [7], we were able to show in an A/B study that VR experiences have a higher potential in achieving a high level of user engagement, immersion, and also the usability was rated as higher. Due to the high number of participants and the classroom situation, the setup of an A/B split study was not feasible. In this paper, we want to focus on identifying and discussing the potential of a VR setup in a classroom experience and discuss potential use cases with students.

We collaborated with four local schools and recruited two school classes per school to participate in the study. A total of 147 students participated in the experiment. At first, the participants filled out a 30-item pre-questionnaire about their age, gender, and experience with games, VR technologies, and digital learning tools. After that, all participants were given a short introduction about the process and the interaction with the VR devices. We familiarized them with the test environment, the HMD, and the different tasks. The first task was to solve a small assignment using the "*Faraday's Law*" experiment. The second task was to solve an assignment using the "*Huygens' Principle*" experiment. After the tasks, the participants filled out a post-questionnaire. This questionnaire consisted of open-ended questions about their overall experience and the two tasks. In the second part, participants were asked to rate their experience, and their engagement with the learning tools on a Likert scale between fully disagree (1) and fully agree (5). We used the System Usability Scale (SUS) [18] to measure the usability of the system. We aim at iterating the design of the system and interactions with the system and want to track the scale during this process to be able to measure improvements. We used the Computer Emotion Scale [19] to measure how the students' experiences are interacting and learning with the new software. Several open questions were used to gain a deeper understanding of their experience in terms of usability, as well as their ideas for various scenarios and use cases.

C. Participants

All 147 participants (93 male, 54 female) were students of four different Austrian schools from 8 different school classes. The students were aged from 14 to 20 (M=16.29; SD=1.28). 51 of the participants were wearing glasses or contact lenses.

We asked each student to rate their previous experience with computers, video games, and VR on a Likert scale ranging from low (1) to high (5). Most of them reported to be experienced using computers (M=3.3; SD=0.98) and also video games (M=3.3; SD=1.41). Most of them were not experienced with VR (M=1.83; SD=0.99). Most of them would play video games often (M=3.25; SD=1.58), 113 mentioned that they like playing video games. Their most popular genres were action (81 students), strategy (58), role-playing (51), and adventure (51). One hundred (68%) of the participants mentioned that they have already heard before of devices such as Oculus Rift or HTC Vive. Twenty-nine participants have already used the Oculus Rift, 15 the Google Cardboard, 24 the HTC Vive, and 19 the Samsung Gear. No one has ever tried the Hololens. Ten have experienced cybersickness before when using an HMD.

When we asked them about their experience with e-learning tools, they mentioned Youtube, Babble, Moodle, Easy4Me, Drops, or Phyphox. When we asked them if they would use simulations of experiments for learning, only 8 answered "yes". When we asked them if they think that VR for learning physics is a good idea, 126 answered "yes".

[3]https://www.vive.com/

V. Results

In the following sections, the results with a focus on usability, engagement, and immersion, the learning experience, and also the potential of various use cases are presented. Not all students finished all questionnaires or wanted to answer specific questions.

A. Usability

Participants were asked if they felt sick or dizzy when using the VR experience. 112 answered the question with "no", 30 answered with "yes". The students were asked about their emotions during interaction with the new technology. Therefore, the Computer Emotion Scale was used to get an understanding of the emotions happiness, sadness, anxiety, and anger. As illustrated in Table I, the rating of emotions referring to happiness (e.g., satisfied, excited, curious) was high (2.37, SD=0.12, where 3 is the highest rating) and sadness, anxiety, and anger were rated as very low. 98 students completed the SUS. The SUS results in a score of 72.6. SUS scores have a range of 0 to 100, and a score above 68 can be considered above average usability. Comparable results have been achieved and discussed in more detail in [7]. These results are also reflected in the open-ended answers of the learners. We asked the students about their experience with the controllers and the interaction design. Most students did not experience any problems with either. Some mentioned that they needed a few minutes to get used to the new form of interaction with the controllers. Some mentioned that the form of locomotion (teleportation) was new and felt unusual.

TABLE I
RESULTS OF THE 12-ITEM COMPUTER EMOTION SCALE ON A LIKERT SCALE BETWEEN 0 (NEVER) AND 3 (ALWAYS).

Happiness	2.37	0.12	Satisfied, Excited, Curious
Sadness	0.29	0.09	Disheartened, Dispirited
Anger	0.15	0.05	Irritable, Frustrated, Angry
Anxiety	0.42	0.14	Anxious, Insecure, Helpless, Nervous

TABLE II
LEARNING EXPERIENCE RATED BY THE STUDENTS ON A LIKERT SCALE BETWEEN 1 (NOT AGREE) AND 5 (FULLY AGREE). X REFERS TO THE VR PHYSICS EXPERIENCE

	AVG	SD
I would like to learn with X	3.74	0.77
It is a good idea to use X for learning	4.04	0.91
X is a good supplement to regular learning	4.07	0.94
I learned something with X	3.48	0.52
X makes the content more interesting	4.14	0.99
X makes the content easier to understand	3.69	0.66
X makes learning more fun	4.09	0.98
X makes learning more interesting	3.98	0.88
The experience with X inspired me to learn more about Physics	2.95	0.3
Learning with X was more motivating than ordinary exercises	3.93	0.82
It makes course content more interesting to learn about	3.99	0.88
I would rather like to learn Physics with X than with traditional methods	**3.72**	**0.68**
I find regular Physics classes boring	3.43	0.59
Seeing the simulations with VR glasses was engaging	3.83	0.71
Seeing the simulations with VR glasses was interesting	4.19	1.00
Seeing the simulations with VR glasses was more engaging than without	4.13	0.98
I would rather use the Virtual Physics Lab on my Phone (+ VR glasses)	**2.85**	**0.27**
I would rather use the Virtual Physics Lab on my own PC	**3.26**	**0.46**
I would buy the VR glasses and download the Immersive Physics Lab at home	**2.94**	**0.32**
I would like to learn with X in the classroom	**3.70**	**0.69**

B. *Engagement, Immersion, and Learning*

On a Likert scale between 1 (not at all) and 10 (fully immersive), the immersion of the experience was rated with an average of 7.81 (SD=0.98), Table II gives an overview of the students' experience with the VR setup with a focus on learning experiences. The learners have mentioned the experience as especially exciting and "funnier" and have also noted that the VR experience makes learning more enjoyable. Especially in comparison to a traditional learning experience, learners have noticed that VR is more motivating. **They would are more likely to use the application on their PC than on their smartphone. They would prefer to learn at school rather than at home.** The VR Experience has only inspired some to learn more about physics. 100 students said that they would like to learn with VR. 17 said that they would like to learn specific subjects with VR. 24 do not want to learn with VR.

C. *Use Cases in School*

In open questions, we asked the students about potential use cases and how they would like to use virtual reality experiences in school.

How to Use VR in Schools: The following use cases were mentioned by several students and are sorted based on the number of mentions:

- (1) **A dedicated VR room in every school:** Students mentioned that they would prefer using a dedicated VR room for learning. This includes learning as part of the class hours but also learning after school.
- (2) **Weekly class to supplement the learning material with the simulation in VR:** Since the setup phase for virtual reality takes time, many students suggested to use virtual reality scenarios once a week to supplement the learning material learned in this week.
- (3) **Project work 1-2 times per term:** Some students also mentioned the potential to use blocked VR classes as project work one or two times per term to avoid time loss due to the VR setup.
- (4) **Multi-player experience:** Several students mentioned the requirement to learn with peers in a virtual reality setup. Collaborative virtual reality solutions can support the learning process.

What to Learn in VR: Additionally, we asked the students what additional learning experience, specific experiments, and phenomena they would like to see in VR. Several students mentioned the following experiences:

1) Astronomy
2) Chemistry
3) Computer science education
4) Geography
5) History
6) Mathematics
7) Biology/anatomy
8) Engineering in general
9) Music education.

As can be seen, students were especially mentioning subjects from STEM fields to be supplemented with virtual experiences and simulations.

D. *General Comments*

We asked students what they did not like. Some mentioned that they would like to have improved graphics. Especially improved readability of text was mentioned. Additionally, they suggested to include more experiments in the laboratory. Some students reported that they did not like the cable and the heaviness of the device. Some also mentioned that the setup of the VR experience is cumbersome.

E. *Limitations*

This study was not designed as a A/B split study because of the classroom setup in the schools. The goal of this study was mainly to get opinions from a large number of high school students.

VI. Discussion

In this study, we tried to investigate the potential of Virtual Reality in school teaching with a large-scale study with the main target group: learners in high school. In previous studies [6], [7], we have already examined and discussed differences between the VR Experience and the desktop PC-based Experience with a small group of learners and teachers. The essential potential of VR for objects in the area of STEM Education was recognized and discussed, and benefits and drawbacks compared to PC-experiences analyzed.

In this paper, the focus is primarily on application areas, and experiences from the perspective of young students and the virtual learning experience were discussed for the first time with 147 students in 4 different high schools. We found that students find the VR Experience particularly motivating and exciting. They would instead learn with VR Experiences at school than at home. Also, they find them more exciting than traditional teaching methods. These results are in line with previous studies in this field showing the potential of virtual reality environments for learners [20].

In this studies we were mainly aiming at finding various useful use cases for such scenarios. Usability was rated as above average, and only a few students had problems with interaction or nausea. The current status of VR technologies was seen as problematic by some. This includes the duration of the setups, graphics, and also the weight of the glasses and cables. Especially setup time and usability of current HMDs was a key element for learners to suggest use cases, which enable learners to save time. Students mentioned that they would rather use virtual reality at school than at home for learning. Also, they would prefer learning with PC-based VR experiences (such as with the HTC Vive) over installing VR apps on their own mobile phones. As a result, it is highly important to identify and describe proper use case scenarios for learning with room-scale VR experiences in schools. Based on the interviews with the students, we were able to define four different use cases for learning with VR in schools: (1) the introduction of individual VR rooms in each school, (2) weekly VR sessions to support school teaching, (3) semester project work, (4) multi-player experiences. Students were also asked about possible application cases for VR. Here it is interesting to see that almost all answers see VR as a potential addition to STEM subjects such as chemistry, computer science, or mathematics.

In future studies, it is crucial to implement, evaluate, and discuss the identified use cases to find proper pedagogical models which are applicable in school and classroom settings and usable by learners and educators.

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