An Educational Physics Laboratory in Mobile Versus Room Scale Virtual Reality - A Comparative Study

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Abstract. Despite year-long efforts in education, studying and understanding physical phenomena still proves to be a challenge to both learners and educators. However, with the current rise of Virtual Reality experiences, interactive immersive simulations in 3D are becoming a promising tool with great potential to enhance and support traditional classroom setups and experiences in an engaging and immersive way. The paper describes the evaluation of the physics laboratory Maroon presented on two distinct VR setups: first, a mobile and cost-efficient but simpler VR experience with the Samsung GEAR and second, a more interactive room scale experience with the HTC VIVE. First results of both preliminary empirical studies indicate that the VIVE environment increases user interactivity and engagement whereas the GEAR setup benefits from portability and better flexibility. In this paper we discuss device-specific design aspects and provide a comparison focusing on aspects such as immersion, engagement, presence and motivation.

Keywords: virtual reality, immersion, physics education

1 Introduction

The improvement of science education is still a topic under frequent discussion in the world today. In physics education in particular in, the situation is twofold: many teachers are challenged in teaching concepts to an increasing number of students, who in turn often face issues themselves in trying to understand the concepts taught while linking theoretical formulas to natural phenomena. Engaging and interesting students in this increasingly relevant issue in our educational system is thus matter of the utmost importance. Emerging technologies, such as virtual simulations and laboratories in VR provide novel ways to engage and interest students in class while at the same time also giving educators more possibilities to create and improve classroom experiences.

Simulations and dynamic visualizations can be used to make invisible concepts visible, stretch time and space, and conduct dangerous or even impossible experiments [2, 14]. While earlier studies suggest that the use of simulations can enhance the understanding of such conceptual topics [1, 3, 8, 21], achievement of student engagement, enthusiasm, and curiosity is still challenging. Gamified and interactive laboratory experiences as a tool have been shown to increase learning outcomes in an engaging way compared to traditional methods [4, 16]. Especially the current interest in VR technologies, in particular cost-effective versions such as mobile virtual reality head mounted displays (HMD) (e.g. Samsung Gear VR, Google Cardboard), can open up new possibilities of engaging in-class learning and remote learning. Additionally, rather expensive current state-of-the-art devices such as HTC Vive provide room scale technologies to support and enable fully immersive experiences in VR, which might be particularly useful for all kinds of educational scenarios, which require a more immersive, interactive, and hands-on exploration of learning environments.

The objective of the research described in this paper is to propose an immersive and engaging form of physics education, which combines effective physics simulations with an engaging and interactive virtual reality experience and also to compare the potential of mobile VR technologies with room scale experiences in order to provide recommendations for use cases. Preliminary qualitative tests of the environment were performed with a small group of students to evaluate the effectiveness of the environment itself in engaging students, checking the learning potential, and usability of such mobile VR systems, which support only interactions with gaze or taps on the HMD compared to more advanced systems with additional hardware in a room scale environment. The final aim of this research is to evaluate such experiences as opportunities for greater student engagement in learning physics.

With this work we aim to discuss the potential of mobile and room scale VR headsets through making the following contributions:

1. Design and implementation description of a physics laboratory for a mobile and a room scale VR experience
2. Two case studies to examine differences in immersion, usability, and engagement and discussing benefits, issues, and interesting use cases of both implementations

In the following sections we will first discuss related work on STEM education with focus on virtual reality experiences. After that we shortly describe Maroon, the virtual laboratory developed for the experiments. In section 4 two different user studies on mobile and room-scale experiences in VR are presented.

2 Related Work

Designing STEM education in an interesting and engaging manner still represents a challenge. One successful pedagogical method for teaching practice in regular classrooms is "active learning". In this method, students not only listen passively to the concepts, but they are also directly involved in the learning process. This has been shown to be an effective strategy for increasing the students performance compared to traditional methods [10, 15]. In physics education a crucial element of the learning process is understanding various phenomena. In active learning approaches for physics education students, one way to teach abstract concepts is the interaction with these concepts through computer-based visualizations or animations, which make unseen phenomena visible and also to allow small experiments [9, 14]. Simulations have been shown by Wieman and Perkins as more effective, safe, and cost-efficient compared to traditional experiments [20].

Other successful virtual teaching methods include physic laboratories in digital form. virtual or remote laboratories facilitate conducting dangerous, expensive, or even impossible experiments [6]. Such tools as part of an educational model either in a remote or an in-class setup can make learning physics more effective, interesting, and engaging [20].

However, while these environments are often a successful learning tool they often fail to engage and convince students about the "fun" elements of this field.

In a large-scale study with 306 participants Corter et al. [6] examined the learning outcomes and student preferences for hands-on, remote, and simulated laboratories and found that learning outcomes after performing remote or simulated labs were as high or higher compared to hands-on labs. Students rated virtual labs as more convenient and reliable, but would prefer hands-on experiences. The feeling of physical presence in a lab was still rated as important factor of engaging laboratory experiences. In [12] the authors investigate various educational efforts in learning labs and conclude that such "alternative access modes must be considered pedagogical alternatives, rather than simply logistical conveniences" and point out the importance of a focus on pedagogical and interaction design. Especially in different VR environments, emotions and activities are perceived in a different way and it is crucial to consider different design aspects for the various VR technologies [19].

A playful form of virtual laboratories has been tested in the field biotech education by Bonde et al. [4]. They tested a laboratory designed with gamification elements and found that this form of environment significantly increased the students learning outcomes and their performance compared with traditional teaching. Another form of more interactive and engaging learning in such a virtual physics environment is described in [18]. The authors describe a collaborative setup for physics education, where students are able to work together on experiments and discuss simulations. In a study it was shown that the collaborative aspects was rated as important, however, engagement and immersion is subject to improvement. One way to improve the interface with engaging elements the the use of gamification. In [17] the authors describe simulation design with such game-based design tools.

In many of the above discussed environments, the lack of immersion and engagement was noted. However, in this digital and playful time, engagement, immersion, or even flow [7] are described ever more frequently as factors for creating interesting experiences. Immersion can be described as feeling of being part of the experience [5]. There is a ongoing discussion about the professional reality in remote and virtual laboratory experiences [13]. Adding immersion as main concept to the learning experience could be used to add new ways to create professional and interesting working and learning environments. The use of virtual reality headsets and technologies is a promising way to create a more immersive, engaging, and interactive environment. With the current efforts to produce VR headsets which are affordable for private users (e.g. PlayStation VR, Samsung Gear VR, HTC Vive), VR is also becoming more attractive as a tool to enhance classroom experiences. Several studies have looked into the potential of virtual reality (VR) for educational scenarios.

In this paper, we introduce Maroon, an interactive immersive physics laboratory, integrated with (1) the interactive virtual reality technology HTC Vive, supporting in-room movement and a two controller setup and (2) a mobile setup with the Samsung Gear VR.

3 Maroon - The Immersive Physics Laboratory

The immersive physics laboratory Maroon (see Figures 3 and 3) was designed as a reduced and simplified showcase of an interactive educational physics laboratory with a subset of educational experiments to evaluate usability and user experience in VR and to measure factors such as engagement, immersion, and learning progress. With the Samsung Gear VR and the HTC Vive, we have selected two very different high in demand, state-of-the-art VR devices to base the comparative evaluation on to investigate on the one hand a mobile virtual reality experience (Maroon Mobile VR) and on the other a fully immersive and interactive room scale VR experience (Maroon Room Scale VR).

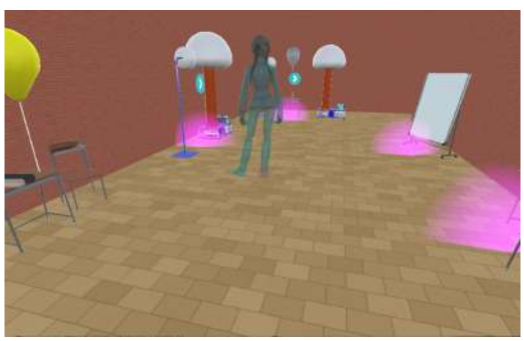

Fig. 1. Lab overview

3.1 The Design

As our research on Maroon includes two studies, the development of the laboratory was also done in two stages. In a first step, a prototype was developed

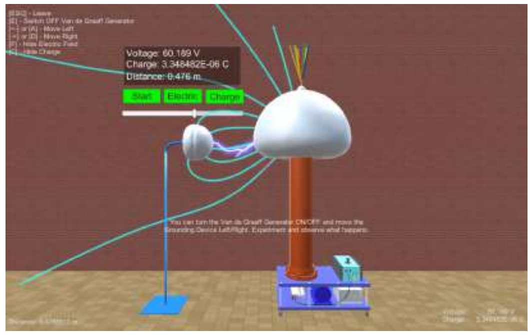

Fig. 2. Van de Graaff Experiment

in Unity3D[3]. Unity supports stereoscopic rendering for different VR devices, including the Samsung Gear VR. For the HTC Vive, the official SteamVR [4] plugin and framework was used. This lab prototype was the design basis for the two VR variants. From originally six implemented simulations in the context of electromagnetism for this setup, only two were integrated in this initial prototype for the study.

In our setup, users can experience VR in two distinct ways on two conceptually different devices: either through a mobile, more light-weight setup (Samsung Gear VR, using the Samsung Galaxy S6) or a more graphically rich, advanced room scale system tracking both HMD and controllers (HTC Vive using two controllers). In particular for user interaction, navigation, manipulation and selection of UI elements with the virtual world, two different design approaches were chosen, considering various limitations and the different design of these two VR devices.

The version of the immersive physics lab Maroon as introduced is designed to support both mobile VR systems such as Google Cardboard or Samsung Gear VR [5] running on mobile phones as well as more advanced setups with roomscale VR such as the HTC Vive[6]. The designed interaction with the environment and the experiments is mostly performed through gaze for the Samsung Gear VR and via controllers for the HTC Vive. Samsung Gear VR additionally provides possibilities to interact through touch and slide input, whereas the HTC Vive benefits from several buttons on both its tracked controllers which can be specifically programmed and also visually adapted for individual user actions. The navigation designs for the two VR alternatives are discussed in more detail in the following.

[3] http://www.unity3d.com
[4] http://store.steampowered.com/steamvr
[5] http://www.samsung.com/global/galaxy/gear-vr/
[6] https://www.htcvive.com/

Navigation Design in Mobile VR Given the Samsung Gear VR system with the smartphone inserted into a head-mounted gear, a real-life like user experience is achieved through a combination of eye gaze, a virtual avatar and a touchpad mounted on the side of the device, with user actions such as double tap, long press and swipe to rotate. Here, the user controls are mostly designed for gaze and tap interactions. An avatar (see Figure 3) is controlled with a gaze point to move through the laboratory. The avatar is always placed on the gaze point - the center of the screen - and can be moved by moving the gaze. Simulations can be started by moving the gaze cursor to the interaction button. Movement is designed as teleporting the avatar to different locations. Sliding (only supported by Samsung Gear VR) can be used optionally to rotate the character or to move specific controls (sliders) of experiments.

Navigation Design in Room Scale VR In contrast, the HTC Vive system consists of a larger HMD connected to the PC as well as two additional controllers, which include a highly-sensitive touchpad and individually programmable buttons with haptic feedback for improved user interaction within virtual worlds. Each hardware element in the Vive setup is tracked by two base stations named lighthouses, thus eliminating the need for an avatar and further enabling the user to move around freely for a more immersive room-scale VR experience. Simulations are started by entering a portal-like object through button press on the controllers. Movement as in teleporting is achieved by pressing the touchpad on one of the controllers, which in turn acts like a pointer, as the user aims at the preferred target and displays a precise colored beam for visual orientation.

Concerning the experimental setup, the main difference between the implementation for Samsung Gear VR and HTC Vive was the addition of interactable objects in the HTC Vive version and its lack of a virtual avatar which was instead implemented in the Samsung Gear version for better usability. By using several programmable controller buttons as well as touchpad press, HTC Vive users are able to benefit from further real-life like interaction possibilities. The necessity of a virtual avatar was not given for these since users carry both HMD and controllers which are being tracked by the lighthouse system.

Interactivities in the Lab The main interactivities integrated as experimental immersive setup for the study are as follows: a virtual laboratory room with different "stations" containing experiments or interactive activities (see Fig. 3), two experiments with a Van de Graaff Generator [11] which, combined with a balloon or a grounding device respectively, simulates electric fields while visualizing field lines as well a display of voltage and charge (see Fig. 3), and interactions with the controllers or the touchpad such as starting the experiment or teleporting. While the HTC Vive to some extend supports movement in the real room, the laboratory was designed as large-room experience; thus a teleporting functionality was necessary for both devices to reach all stations. Based on these interactivities 3-5 main educational experiences were included in our study setup of the virtual physics laboratory: (1) an experiment with a Van de Graaff Generator and a balloon, where charges, electric fields, and field lines can be visualized, (2) another experiment with a Van de Graaff generator and a movable grounding device where charges, electric fields, and field lines are visualized (see Fig. 3) and (3) a whiteboard with information and labeled pictures to explain the theory behind the Van De Graaff experiments. In order to showcase the manifold possibilities of user interaction with virtual objects using controller mechanisms, the HTC Vive version of this station additionally features an interactive playground with different textured objects such as throwable and grabbable cubes and metal balls. (4-only HTC) A triboelectric experiment with two rods and one balloon as well as a miniature version of the previous Van de Graaff experiment, however, this was only fully implemented for the HTC Vive test setup. Hence, to achieve more diversity in our experimental setting, this specific station was replaced by another station on the Samsung Gear VR version where it features a laptop with an interactive, feedback-supported quiz session in order to test the theoretical knowledge users should have gained with their practical hands-on walk-through of Maroon Mobile VR. (5-optional) Additionally, an accurate model of a Tesla transformator can be found by users as a hidden "easter egg" by further exploring the virtual laboratory world.

In our research, these two conceptually different VR setups provide the frame for our implementation of the interactive immersive physics laboratory. Ultimately, the goal in developing these simulations is to let users act more or less the same way they were would if placed in a real-life physics laboratory. As of now, users are - to some extent - able to immerse themselves into this world while being shielded from (visual) influences of their actual physical surrounding. As such, immersive 3D has shown to be a beneficial aid to present difficult concepts in physics, such as the effect of switching a Van De Graaff generator on and off.

4 User Studies

We performed two preliminary user studies with a total of 17 participants to evaluate the system and the experience. In a first study (with 9 participants) we focused on testing the Maroon with the mobile setup only. In the second study (with 8 participants) we focused on evaluating (1) engagement, (2) immersion, (3) learning experience, (4) virtual reality experience, and (5) usability and user experience in comparison to a more interactive VR experience with the HTC VIVE.

4.1 Material and Setup

The VR setup for Samsung Gear VR consists of the following hardware components: mobile HMD and smartphone Samsung Galaxy S6. Figure 3a shows the Samsung Gear VR with the attached mobile phone. The setup for HTC Vive contains the HMD itself, cables and two base stations as well as two controllers.

For a room-scale setup setting, we provided an area of about 2m x 2m. Furthermore, a powerful high-end hardware PC is necessary. A mobile VR setup was chosen in order to support a widely accessible and cost-effective way to interact with the laboratory, which could be used in classroom environments (e.g. guided by an instructor), or for self-regulated learning at home.

(a) (b)

Fig. 3. Samsung Gear VR and HTC Vive setup

4.2 Method and Procedure

For the first study with Samsung Gear VR, we first asked the participants to fill out a pre-questionnaire. The pre-questionnaire was used to get information about the participants experience with virtual experiences, and VR technologies, and their expertise in physics. They were then were introduced briefly to the system. After this they were asked to use the Maroon Mobile VR with the Samsung Gear VR. After the experience, the participants shortly described their impressions in form of an open dialog. Finally, they were asked to complete a post-questionnaire with 10 open-ended question on the experience and 20 single-choice questions with ratings on a Likert scale between 1 (fully disagree) and 7 (fully agree).

In the other extended study with both devices, participants were required to fill out a short pre-questionnaire with standard personal background information, followed by a brief introduction to the experimental setup. The main goal was then to complete consecutive tasks in the immersive lab Maroon, which were announced by the study moderator during the test run. Since we examine the differences and similarities of both devices, our eight test subjects were divided into two separate groups of four persons each for the purpose of AB / BA testing where users test both devices in reverse order. (Specifically, four users tested the Vive first; whereas the other four tested the Samsung Gear VR first.) After each single run, users completed a corresponding post-questionnaire containing 19 standardized questions from the Game Engagement Questionnaire (GEQ, [5]) to measure the level of engagement based on absorption, flow, presence, and immersion, as well as ten open-ended questions on the experience and 20 single-choice questions with ratings on a Likert scale between 1 (fully disagree) and 7 (fully agree). For a comparative evaluation, all subjects had to complete a "combined" post-questionnaire with open-ended questions about their experience on both devices at the end of the experiment.

4.3 Participants

Experiment 1 In the first study 9 students (2f) between 23 and 27 (AVG=24.78; SD=1.47) tested Maroon Mobile VR. All students were in the field of computer science or electrical engineering and rated their experience with computers very high. 6 students rated their selves on a Likert scale between 1 (not at all) and 5 (fully agree) also as very experienced in the usage of video-games (AVG=4.11;1,17), 8 like playing video games. All of them rated themselves as not very experienced in the usage of VR (AVG=1.78;0.97). 7 had heard of mobile VR devices before, 4 have used Google Cardboard, 5 the Samsung Gear VR. Rating their physics expertise the results were very mixed (AVG=2.89;1.05).

Experiment 2 In the second study 8 (1f) participants were asked to test the mobile (Maroon Mobile VR) and the interactive physics lab (Maroon Room Scale VR). 7 are very experienced in the use of computers (AVG=4.38;1.41), only 2 in the usage of video-games (AVG=3;1.2), and only 1 in VR (AVG=2.25;1.39). 4 have used a mobile VR setup before, nobody the HTC VIVE. 7 rated their physics knowledge a 3 or below (AVG=2.63;0.92).

In the following sections we discuss different aspects of the outcomes of the post-questionnaires and the interviews. The individual aspects will be mainly described by including outcomes of the questionnaire and direct quotes describing the students impressions and experiences. An overview of the results can also be found in 3.

4.4 Experiencing Immersion and Engagement

Most of the participants said they find learning in this manner more engaging (AVG=6.67; SD=0.82) and fun (AVG=6.33;0.82). When being asked if they find it engaging and motivating, most of them agreed: *"very motivating way of demonstrating stuff"*. The lack of content and variety was mentioned as a drawback here: *"Not yet, but I can see how the concept would be engaging once more variety exists."* When asked what they liked about the system, immersive and three-dimension characteristics were mentioned in particular: *"Immersion makes me remember stuff better"*. The VR experience was received very positive and described as very immersive. In the second part of the study we compared presence, absorption, flow, and immersion between interactive VR experience (with the HTC Vive setup and the mobile setup. As seen in Fig. 6 the interactive version achieves only slightly better results in all 4 categories.

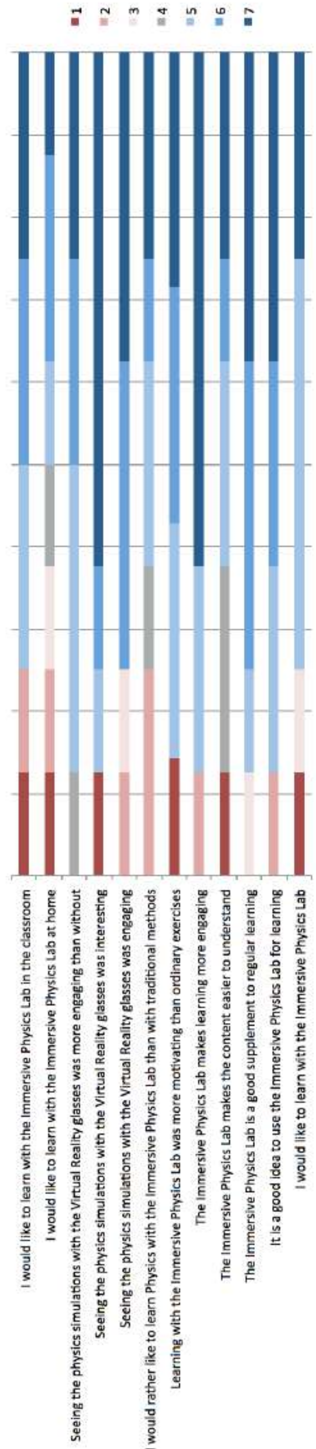

Fig. 4. Survey results of experience with Maroon Mobile VR between 1 (not at all) and 7 (fully agree) in GEAR VR

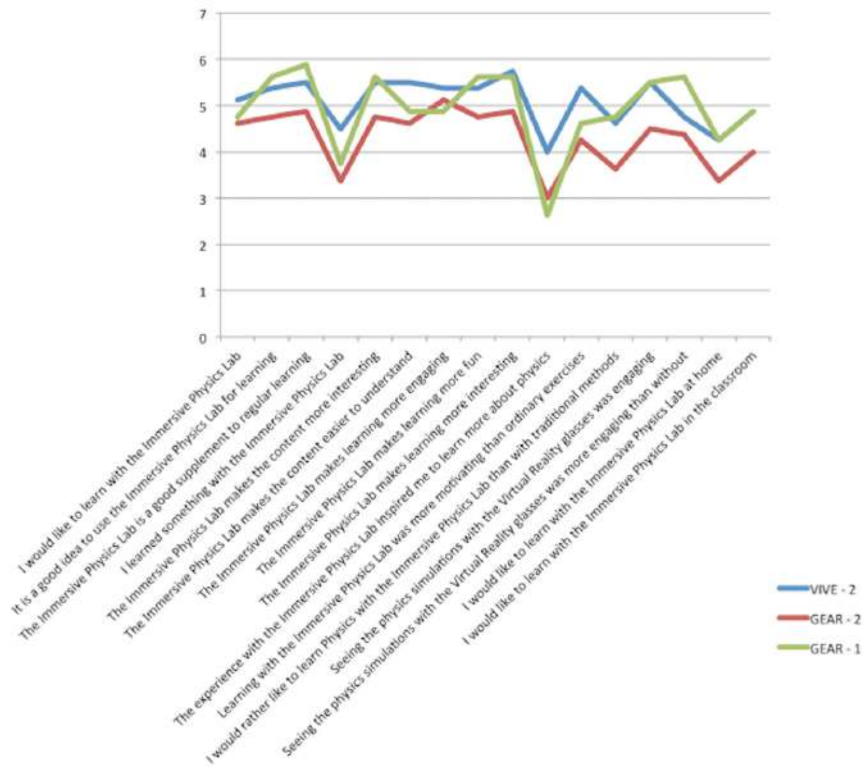

Fig. 5. Comparison of survey results of experience with Maroon VR between 1 (not at all) and 7 (fully agree) between experiment 1 with Gear VR and experiment 2 with both devices

4.5 Experiencing Learning

In the first part of the study, on a Likert scale between 1 (not at all) and 7 (fully agree) most of the people questioned said they would like to learn with Maroon Mobile VR (AVG=5.33; SD=1.51) and feel that the content is easier to understand (AVG=5.67;1.21) and more motivating than ordinary exercises (AVG=6.0;0.89). However, the environment inspired only a few to learn more about physics (AVG=3.17;1.33). When we asked them if they would use it for learning, all but one of the participants were positive about this idea. Many positive comments mentioned the experimentation and visualization of usually unseen things: *"I would use it immediately for my mechanical engineering studies, because it is an advantage to see and rotate the machines in a 3D space; also it can be an advantage when learning about dangerous machines: one can still see everything without a distance"*. It was also mentioned that they would like immersive lab as supplement for learning (AVG=6.16;0.98). The students of the evaluation group would rather like to use Mobile VR in a class-room environment (AVG=5.33;1.86) than at home (SVG=4.5;1.87). *"There are a few elements missing that would produce a good learning environment for me. The first thing are explanations. If someone learns about the illustrated concepts beforehand (maybe in a class), the game could certainly help with that, but it is far from a standalone learning tool right now."*. Concerns using this system for learning include the topic choice (*"It's good for demonstrating something, maybe not as good for learning facts etc., because you can't for example take notes etc."*) and additional overhead. The VR aspect was very well received for learning. Participants thought it was engaging to see the physics simulations with the VR glasses (AVG=6.5,0.55) and also a bit more engaging than without VR (AVG=5.83;0.98) *"learning with VR is gonna be awesome and I never thought about what happens to a balloon if we place him between a Tesla-coil and a grounder. Funny"*.

In Fig. 5. we compare the above mentioned results with the results of the second part of the study. Again, we can see that the interactive VR experiences achieved slightly better results compared to the mobile experience. However, in the first experiment with the mobile device only, the results were slightly better for the mobile setup compared to the second experiment. This could explained by a bias through the interaction with the HTC Vive setup.

4.6 Experiencing Usability and User Experience

While some of the people had no issues with the controls and the interface, others had problems here, especially with learning the movements. Minor usability issues were mentioned. These included in particular the unusual movement (teleporting instead of walking; how to turn the avatar) and interactions (e.g. clicking twice on the door to exit a simulation instead just once). *"Moving in the environment was not very intuitive, but worked well. The UI was not very hard to figure out."* Additionally, the idea to give more feedback on interaction possibilities was mentioned *"I wished for some visual feedback on what's clickable. I wasn't sure what I can click and what not so I clicked around quite a lot."*

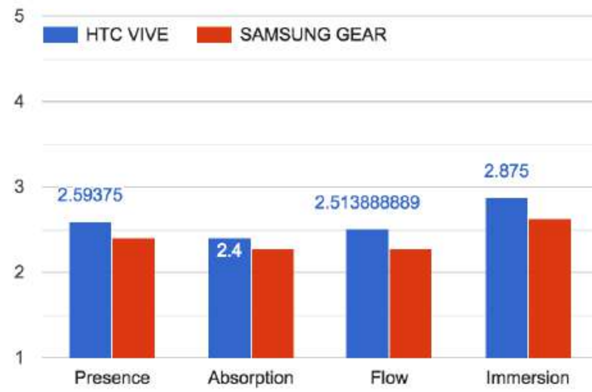

Fig. 6. Comparison of GEQ

4.7 Concerns and Improvements

Concerns and ideas for improvement were mainly in the areas of usability and controls, graphical interface, and more content. The low resolution of the VR experience was mentioned as a drawback by some students. *"If the target group is Cardboard users then theres not much to improve graphics wise I think. Maybe having a narrator voice explaining things or physic concepts to the user would be nice."* Several participants mentioned that they would like to see more experiments and simulations in the world and that the lab still looks very empty *"I think one can learn a lot, however, many experiments or models are required for that"*, *"It was nice, a bit empty, not very realistic looking, but nice." "the VR technology itself needs to be improved. Higher resolution and lenses will make a huge difference. The game it self was, except of some teething troubles, well done. The controls are good, maybe improvable with a controller. But all in all I liked it."*

The study was designed to get insights to improve the current prototype with focus on engagement, immersion, and learning outcomes. The first study only focuses on testing the mobile experience and was also used to evaluate the VR study design for the second study. Based on these finding, the prototype will be updated and a large-scale study with more participants is designed.

5 Discussion and Conclusion

In this paper we have described an immersive learning environment for physics education based on interactive physics simulations. First results report very positive experiences with the environment. The Immersive physics laboratory was described as a very engaging experience, which participants would be in favor of using for learning and which they find more engaging and also effective compared to traditional learning scenarios. The participants would recommend the use of such tools rather as supplement to traditional in-classroom learning experiences than as a stand-alone tool for self-regulated learning at home.

The results suggest that such interactive and immersive experiences have the potential to become an integral part of future learning. The use of VR devices as learning device can change guided classroom learning and self-regulated learning at home. More specifically, our first results also suggest that interactable objects such as a balloon or a ball placed in the virtual world can actually enhance the feeling of total immersion with users.

Due to the mobility and cost-efficiency of the mobile VR setup (Maroon Mobile VR), this form of VR lab can be used to extend the classroom learning with small in-class exercises as part of active learning strategies. In an application scenario, all students could use it at the same time, while the teacher makes remarks and talks about the concept. It could also create a new way of making remote learning exercises more interesting. The room scale setup (Maroon Room Scale VR) was experienced as more immersive, but it requires a lot of space, however, and due to the hardware requirement it is very cost-intensive and only one student could use it at a time. Thus, this setup could be used as part of a self-directed learning room for students to learn after class.

We have described preliminary tests on a first simplified prototype of the laboratory with several simulations. The lack of further simulations and interaction possibilities was mentioned by the participants and had influenced the study results. To fully explore the potential of such environments we are currently extending the laboratory with other forms of simulations with different educational goals. Additionally, we are planning to study further the effects on learning of the VR experience of the laboratory, also in comparison to the same desktop experience.

Acknowledgment

We would like to thank *John Winston Belcher* from the Department of Physics Massachusetts Institute of Technology for supporting this research. The Maroon projects is a research project at *Graz University of Technology*: `gamelabgraz.com/maroon/`. We thank all people who are and were involved in the development process.

We would also like to express our gratitude and appreciation to *Philip H. Bailey* for his constant (also last minute) support.

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