



Developing Virtual Simulation of Optic Lab in Physics Education using Virtual Reality

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Abstract. As virtual reality (VR) technology improves, the impact VR has on other areas, such as education, also improves. Educational VR applications provide support to students with an immersive environment in which such an environment may not be available. This paper as a student project focuses on the development of an educational VR application focused on the topic of optics. Ideas like collaboration between computer science students and physics educators, accessibility, and learning theories are explored. A pilot study with six participants was conducted, offering insight into the effectiveness of the educational VR application. The results gathered from the pilot study, limitations faced, and future research directions discussed offer a basis for researchers interested in educational VR work.

Keywords: Education, Virtual Reality, Immersive Learning Tools.

1 Introduction

Education is constantly improving as old teaching methods are enhanced or supported by new ones. The development of technologies has the potential to enhance, support, and create new teaching methods that could help students learn. Virtual reality (VR) is a rapidly evolving technology with immense potential in various domains, including education. The integration of VR in education represents a transformative approach to teaching with the creation of immersive learning tools like educational VR applications. Existing research highlights the interest of students in using VR for learning and the need for content tailored to educational purposes [1, 2]. Educational VR applications can focus on one topic, creating an immersive experience unique to other teaching methods [3–6]. VR has demonstrated substantial promise in education, with research showing improved student engagement and understanding in subjects ranging from chemistry to physics. Recent studies underscore VR's transformative potential in STEM education, particularly in replicating intricate lab environments [4, 5].

This research aims to develop an educational VR application and investigate its immersive and usability. The developed educational VR application will be focused on the physics topic of optics, exploring the laws of reflection and refraction and their applications to a beam of light. There are three activities in the educational VR applications that help explore the laws of reflection and refraction while providing a puzzle-based scenario where a light beam is required to hit a target so the user can continue. A user-testing session was conducted with a small group of participants to investigate the immersive and usability of the educational VR application. The participants provided feedback on the educational VR application after completing the activities.

2 Related Works

Research has found that students are interested in educational VR experiences [1, 2]. The study done by [2] found that students were motivated by their experience in an immersive educational VR application and hoped for more in other educational topics. Such motivation could bring interest to some topics that otherwise would be avoided. The inherent interest in educational VR applications provides a strong foundation to pursue research. Another study by [7] found that cognitive processing, attention, engagement, and critical thinking produced in a VR environment were more significant and on par with traditional teaching methods, providing a ground basis of

validity for educational VR applications. Memory retention is key when learning, and [8] found that the interaction between the user and objects in the VR applications helped to develop this retention.

Students would not be the only beneficiaries of educational VR applications. [2] identified that laboratory equipment is costly to set up and acquire, whereas VR applications would be quicker and, in most cases, cheaper. VR equipment, such as headsets, is improving yearly and staying relatively affordable. With the release of the Meta Quest 3S by Meta, it shows that there is a trend to continue to make VR headsets more powerful and more cost-effective. A VR headset can house many educational applications, which makes the headset versatile.

Studies investigating VR [4] in chemistry education show that immersive environments significantly improve students' understanding of complex concepts and retention rates compared to traditional teaching methods. Their findings resonate with this study's premise, emphasizing the potential of VR to transform STEM education by offering experiential learning opportunities that are otherwise difficult or costly to replicate in physical labs.

Several learning theories have been applied to VR implementations. Some of these theories include constructivism, cognitivism, scaffolding, and experiential & active learning [9–11]. Constructivism involves a high-fidelity VR environment where learners solve real-world problems, like stacking cubes or operating equipment, and cognitivism ensures that only the necessary information is displayed to avoid distractions in the simulation [9–11]. Scaffolding means that the user starts with more straightforward tasks to get accustomed to VR interactions before attempting more complex tasks, and experiential & active learning allows users to freely interact with objects and receive feedback, which enhances their engagement and assessment [9–11]. The educational VR application that was developed for this study includes these theories to ensure the best possible experience for the user since it would hopefully increase engagement, learning, and lower the cognitive load.

Educational VR applications in collaboration with educators ensure accuracy and relevance to the curriculum [1, 3]. Collaboration with domain experts helps educate the developers, enhancing the quality of content produced in the educational VR application. Educational VR applications inherently promote cross-disciplinary collaboration since the developers are not experts in the field the VR application focuses on, which furthers education through new teaching methods that benefit students' learning.

This paper aims to make an educational VR application that provides an immersive and pleasant experience that can potentially substitute the need for physical lab equipment to help educators and support student learning. The application by [3] and [5] focuses on physics education. Similarly, the educational VR application discussed in this paper is based on physics education but focuses on optics. Many educational applications focus on optics; however, these applications almost always portray light in a two-dimensional space and lack a sense of immersion. We believe that the immersive nature of VR will bring interest to optics and provide a sense of realism as the applications will be explored in a three-dimensional world, allowing full exposure to the content provided.

3 Research Method

This research began as a capstone project, where students independently plan, conduct, and present research under supervision. After discussions with a physics expert and project supervisor, the idea of developing an educational VR application aligned with curriculum goals was approved, and development began. The project unfolded in three phases. The first involved learning Unity's VR development environment and simulating light reflection and refraction for an interactive learning experience. The environment is shown in Figures 2 and 4. This phase also included setting up version control via GitHub, which posed challenges later. With the foundation in place, the second phase focused on user experience and accessibility. Movement options like teleportation and snap turning were integrated to ensure all users, regardless of mobility, could fully participate. One notable user experience and accessibility feature is voice narration, which would assist participants with reading text. The second phase also included technical features such as getting the core mechanic working. That involved getting the Unity line renderer to reflect and refract like light. Figure 3 shows a line renderer being refracted. The final phase refined the application for release, addressing bugs, improving environmental design, and enhancing immersion with a lab-like setting. Testing with six post-secondary students, most new to VR, confirmed the application's educational value and accessibility, underscoring its potential as a transformative learning tool.

When participants start the VR application, they are placed in a tutorial room as seen in Figure 1. The purpose of the tutorial is to help reduce the cognitive load so that the participant is overwhelmed with the topic of optics and VR interactions. Once participants are accustomed to the controls and complete the tutorial, they are teleported to the first activity (see Figure 2). The first activity explores the topic of reflection through images and text with audio to accompany it. Once the participants have finished exploring the topic of reflection, they are presented with a puzzle where they need to reflect light to hit a target. Figure 3 shows a potential solution to activity one. Participants then move on to Activity Two (see Figure 4) once they have completed Activity One. Activity Two explores the topic of refraction using methods similar to activity one and presents a different puzzle requiring the

use of refraction. There is also a third activity, which has a more challenging puzzle and describes the phenomenon of total internal refraction. Once the participants complete the third activity, they are given a short survey on an external laptop. The testing was done in a computer lab with substantial space and helped us gain insight into the participants' experience in the educational VR application. The survey contained all user responses.



Fig. 1. Tutorial Room.

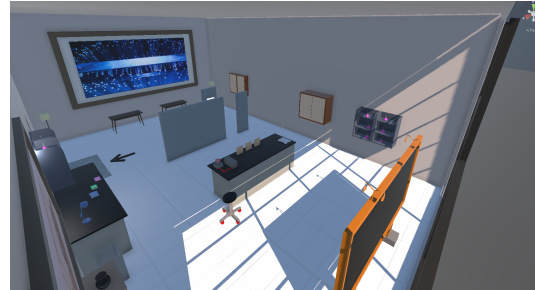


Fig. 2. Activity One.

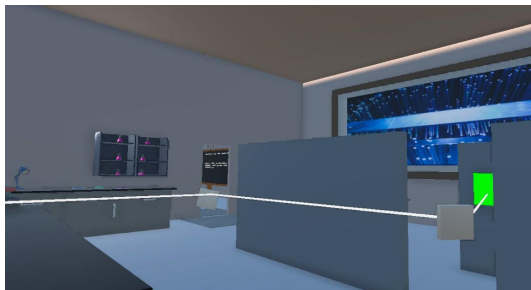


Fig. 3. Activity One Puzzle Completed.

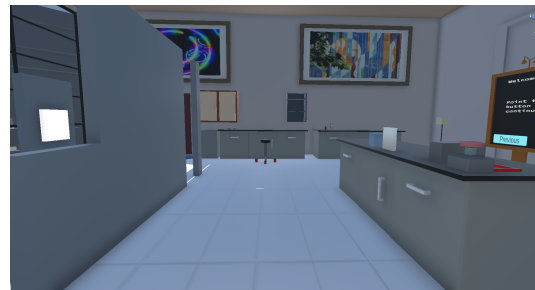


Fig. 4. Activity Two.

4 Result

A pilot study with a total of 6 participants was conducted. All 6 participants were computer science students with little to no VR experience and had high school physics knowledge. It is unknown if the participants had previous knowledge of optics before the user testing since it was not asked, but they had knowledge of physics from high school. However, the user testing conducted was mainly focused on gathering information about the educational VR application, not the participants; therefore, having previous knowledge of optics was not of concern.

The user testing was very successful, and the application received pleasant reviews. Figure 5 shows the results of question 1, which asked the user to rate their overall experience with the interactions, navigation, and accessibility settings. We received an average score of 4.17 out of 5. This result is favorable since the 6 participants had little VR experience and found the controls and navigation trouble-free.

Figure 6 shows the results of question 2, which asked the user how effective the application was at demonstrating the law of refraction. We received an average of 4.83 out of 5. This result is very promising as the whole purpose of the application is to help teach the topic of optics. It also shows that collaborating with a domain expert helped to achieve a successful demonstration of the law of refraction.

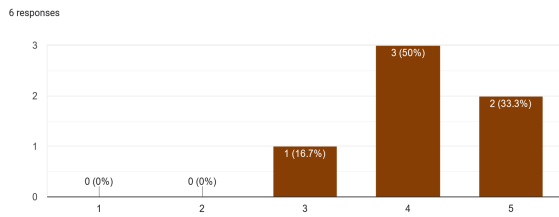


Fig. 5. Question 1 Results.

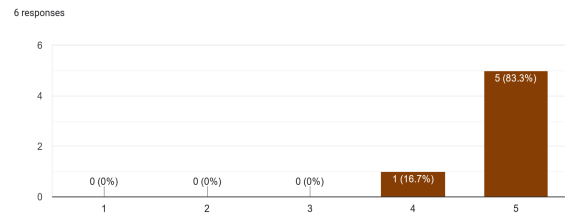


Fig. 6. Question 2 Results.

Figure 7 shows the results of question 3, which asked the user if the VR application helped them better understand the law of refraction compared to traditional methods. We received an average of 4.5 out of 5. This result is also promising as it shows that most user testers believe that the VR simulation helped them better understand the concept than traditional means of teaching. This question was asked as the participants had previous experience learning physics in high school and possible university physics courses.

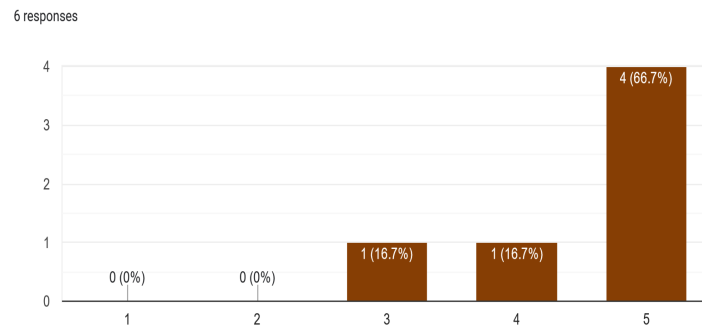


Fig. 6. Question 3 Results.

5 Discussion

The three questions were asked as they provided insights into the educational VR application. Question 1 mainly focused on the participants' experiences, while Question 2 focused on the presentation of the concepts. Both questions offered helpful insight into the effectiveness of the design choices and developed features of the educational VR application. However, Question three was asked if the application helped them better understand the material compared to traditional methods. Although the study did not provide traditional methods, the participants had experience going through traditional learning methods similar to the ones used for optics. The feedback from user testing further reinforced the prospect of using VR technology, as every test case in this study provided positive feedback, and the participants felt the concepts were demonstrated well. The pilot study results indicate the potential future integration of these technologies in education. Another crucial aspect was the accommodation for individuals who could not physically attend the laboratory sections of their university courses. With the future adoption of VR technology, students who cannot be a part of the lab can still access the same lesson for the day in the comfort of their own space. Although the participants were not physics students, their responses are relevant as they are students who have had experience learning a subject matter in a traditional setting.

There are not only net positives for the use of these devices. It is worth noting challenges such as prolonged usage and its effects on people's eyes and addressing the arguably steep learning curve for educators unfamiliar with VR. Discussing the positives and negatives of incorporating a more advanced way of demonstrating concepts with technology is important. However, with the completion of this research, it is clear that virtual reality holds significant potential as a transformative tool for enhancing education experiences, provided its challenges are also addressed thoughtfully and effectively. It is also worth noting that the promising results of this study align with other STEM education studies, where immersive VR environments not only enhanced comprehension but also fostered engagement. This highlights a shared trend across STEM disciplines, suggesting that VR's interactive and three-dimensional exploration capabilities could bridge theoretical and practical learning gaps.

6 Future Work

As the development of the program concluded at the end of November, many features, unfortunately, did not make it to the final product. Such examples include using actual voice narration instead of artificially generated ones and expanding the educational material to cover broader physics concepts such as kinematics. If the application were to be further expanded upon, such implementations would be among the first contenders to be added. Another future goal of this project is to incorporate a digital library of other academic programs to be experienced in virtual reality. Before research on this project began, the project supervisor demonstrated an earlier program of theirs that was similar to ours in that it showcased chemistry topics in a simulated environment comparable to this application. The overarching objective was the compilation of multiple different educational materials in an immersive virtual simulation. The idea would in time, lead to the creation of an all-in-one learning platform wherein any person with a VR device could utilize it as a tool to further their education.

The pilot study lacked diversity and a large number of participants. Currently, there are considerations that the next study will include a more diverse group, including more physics students and more participants. Another consideration for future studies is directly comparing traditional learning methods to the educational VR application using two controlled groups.

There is significant potential to broaden the scope of this application. For instance, the app could integrate with immersive VR learning tools to cover subjects such as biology, where users could explore the human body and cellular processes, or chemistry, where virtual experiments can be demonstrated on the molecular level. These additional components, in theory, would form the foundation of a unified VR learning platform. With such a system, virtual reality education has a promising future of engaging students in lessons tailored to their academic pursuits, which will foster a more engaging and accessible learning experience.

7 Conclusion

Upcoming technologies have the potential to provide benefits to education. VR is a technology with great potential in furthering how institutions teach. As discussed in the paper, the educational VR application helped participants understand the topic of optics, and the controls of the application were not too difficult to learn. The pilot study helped solidify that the educational VR application developed offered a pleasant experience while effectively exploring the topic of optics. Educational VR applications are an effective new teaching method that benefits institutions, educators, and students. As more researchers study educational VR applications and developers produce higher-quality experiences, better VR education will become widely available to students. This study, even though in the pilot stage, reinforces the value of VR as an innovative teaching tool across various STEM fields. By combining immersive design with collaborative development, VR applications can provide accessible, cost-effective, and engaging learning experiences, potentially revolutionizing education for future generations.

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