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Investigating Virtual Simulation of Optic Lab in Physics Education

Haris Kajtazovic[1] and Hossain Samar Qorbani[1]

[1] MacEwan University, Edmonton AB T5J 2P2, Canada
kajtazovich@mymacewan.ca

Abstract. The development of technology opens the opportunity to create new and practical tools to support everyday life. One such developing technology is virtual reality (VR), which has been utilized as a tool to support individuals in different aspects. One such tool developed to support an individual's education is educational VR applications. Educational VR applications should be investigated to understand what makes them practical and appealing. In this extended abstract, as a student's independent research, this study focuses on investigating an educational VR application to gain deeper insight into the usability and effectiveness of the application. The educational VR application being investigated focuses on exploring the physics topic of optics through an immersive laboratory-like environment. User testing was conducted with 16 participants, which offered more profound insight into the optics-based VR laboratory. The results gathered from the user testing, limitations faced, and future research directions are discussed, offering insights for researchers and educators interested in educational applications of VR.

Keywords: Physics Education, Virtual Reality, Immersive Learning.

1 Introduction

Developing technologies have the potential to enhance individuals' everyday lives. Aspects of life, such as work, home, and education, can significantly benefit from new applications from developing technologies. Virtual reality (VR) has the potential to benefit aspects of training and learning. A study by [1] mentions that VR applications can exhibit educational affordances such as spatial knowledge, experiential learning, intrinsic motivation, situational learning, and collaborative learning, which can create a more effective educational environment. Another study [2] found that the application of VR in education creates excitement among individuals. Through planning and research, immersive VR applications have the ability to focus on one topic, offering a unique experience for the individual [3-7].

This research continues a previously completed pilot study on an educational VR application. The previous study explored the development of the educational VR application with a small pilot study, providing an insight into the application's usability. The developed educational VR application explores the physics topic of optics through simulating a laboratory-like environment. The optics-based VR laboratory was developed using Unity installed on a Windows 10 machine and utilizes the OpenXR plugin in Unity for VR camera rig and hand interactions. The optics-based VR laboratory uses Unity's line renderer to simulate a beam of light. Objects with certain scripts simulate the effect of reflection or refraction when interacting with the line renderer. The optics-based VR laboratory contains three activities which all have puzzle-based scenarios that require the user to use the laws of reflection and refraction to bend a beam of light to hit a target. The environment also includes a blackboard object that a user could interact with to learn about the laws of reflection or refraction and gain information about the puzzle.

This research aims to investigate the optics-based VR laboratory's usability and effectiveness in conveying the topic covered in the application. Multiple user-testing sessions were conducted with different participants to investigate the usability and effectiveness of the optics-based VR laboratory.

2 Related Works

Previous research has explored the capabilities of educational VR experiences. The levels of engagement, critical thinking and cognitive processing found in individuals participating in VR activities were similar, and sometimes better than if the individuals went through conventional teaching methods [8]. Another study by [9] found that the memory and knowledge retention improved among participants who used an educational VR application. The benefits of using educational VR applications welcome the idea of incorporating it into training and learning scenarios, creating validity towards educational VR content [8, 9].

The abundance of tested educational VR applications would not only benefit the participants. Research by [2] identified that incorporating VR equipment could lower organizational costs. In most cases, the equipment used for training and learning could be expensive, leading to budget cuts for some organizations [2]. Fortunately, VR equipment is improving and getting cheaper as more manufacturers improve their products while reducing costs. A single VR headset can contain multiple applications, reducing the need for large storage areas that training and learning equipment may need.

Other studies have been done testing the effectiveness of VR in other disciplines. A study by [4] found that immersive environments significantly improve students' retention rates and understanding of chemistry topics. The research done by [4] conveys the premises of this study, to test the effectiveness and usability of the educational VR application. The testing would help us understand how the use of VR in physics education may affect students' understanding of physics topics.

Constructivism, cognitivism, scaffolding, and experiential & active learning are types of learning theories that have been applied to educational VR applications [10–14]. The optics-based VR laboratory being investigated in this paper utilizes these theories to provide the user with the best possible experience. The optics-based VR laboratory utilizes constructivism by including a high-fidelity VR environment of a physics lab that allows users to practice problem solving and applying the laws of reflection and refraction [10-14]. Cognitivism is utilized through the use of interactive blackboards in the optics-based VR laboratory, which allows for necessary information to be presented to the user [10-14]. The optics-based VR laboratory separates the tutorial, first, second, and third activities into parts, allowing the user time to experiment and absorb the information so they can apply the information elsewhere through the application, which utilizes the idea of scaffolding [10-14]. Furthermore, the puzzles in the optics-based VR laboratory are designed to create an environment for experiential & active learning since users are free to interact with the objects that give feedback, like picking up a mirror to reflect light, a cube to refract light, and pushing a button to activate the beam of light [10-14]. With the inclusion of the learning theories in the optics-based VR laboratory, this paper can test how such theories are perceived in a VR environment.

Development of Educational VR applications has been tailored towards STEM education [3-5, 15, 16]. Creating STEM-focused educational VR applications allows individuals to learn in a new way while immersing themselves in a new environment. User testing, along with other forms of validation, helps gauge the effectiveness of educational VR applications and is often conducted by VR researchers. However, a missing aspect in some educational VR applications is the lack of user testing and validation. The applications developed by [15] and [16] provide information about potentially practical VR experience; however, the applications are missing the validation of user testing. This paper aims to test the already optics-based VR laboratory that covers the physics topic of optics to gain a deeper insight into the application's usability and effectiveness.

3 Research Method

This research is a continuation of a previous pilot study and started as a project for an independent research class where students plan and conduct research under supervision. The initial pilot study results were promising, therefore giving grounds for continuing the research with a more diverse participant group. This research was conducted in five phases. The first phase involved planning the research, creating a schedule, looking into necessary documents for ethics approval, creating a questionnaire for participants, and reviewing the pilot study results. The second phase mainly involved getting ethics approval for this research and fixing some bugs found during the pilot user testing. The third phase was primarily volunteer seeking. To spread the word about the research, professors from the computer science and physics departments were contacted to set up dates so that presentations about this research could be given to the students. At the end of each presentation, volunteer forms were given out to all interested in participating in the user testing. The fourth phase focused on completing user testing sessions as each participant communicated a date and time that they were available. Each participant could stop at any moment, but all participants completed the optics-based VR laboratory and the user survey at the end of testing. Once the fourth phase was finished, the fifth phase consisted of data analysis.

The fourth phase focused on user testing sessions, and they were done in a library break-out room designed for VR use. When the optics-based VR laboratory starts, the participant is placed in a tutorial room (see Fig. 1). The tutorial room is designed to give the participant an environment to familiarize themselves with VR controls, objects relevant to the activities, and the interactive blackboard. The interactive blackboard gives the participant the necessary information about the application, activities, and optics learning materials. Each interactive blackboard shows text and images and provides text-to-speech to assist the participant. The tutorial room helps prepare the participant for the upcoming activities, as its purpose is to reduce the cognitive load on the participant, so when they start the activities, the participant can focus more on the puzzle and optics content. The participant can stay in the tutorial area until they are comfortable moving on to the first activity.

Fig. 1. Tutorial room in the optics-based VR application.

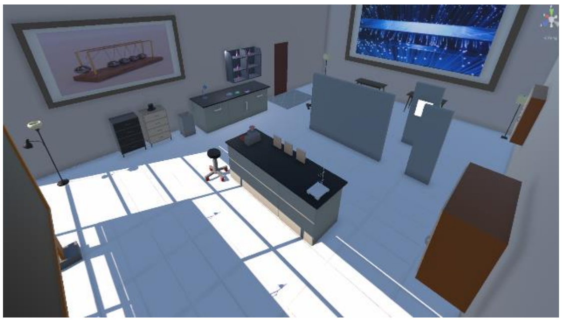

Fig. 2. First activity room in the optics-based VR application.

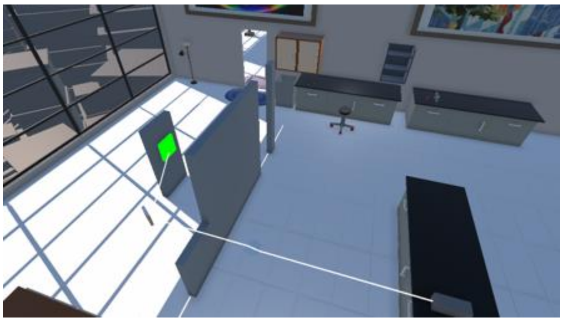

Fig. 3. The second activity room in the optics-based VR application that has been completed.

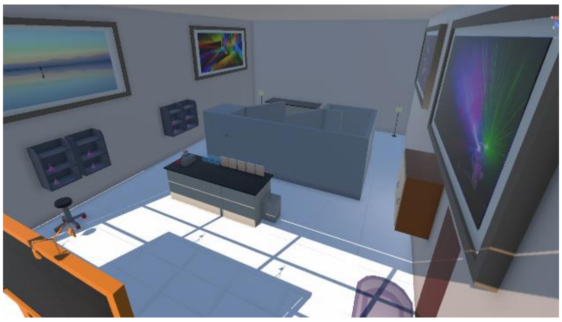

Fig. 4. Third activity room in the optics-based VR application.

The first activity focuses on presenting the law of reflection (see Fig. 2). Images and explanations of the law of reflection are presented to the participant through the blackboard, and once completed they are presented with a puzzle. To start the puzzle, the participant is required to push a button that is on a table in front of the blackboard that will activate the beam of light. Once the beam of light is active, the participant is required to grab and place mirrors to bend the light and hit the white target. Completing the puzzle removes the door located in left wall, plays an audio cue signaling completion of the puzzle, and gives the participants access to the second activity. It is worth noting that puzzles and activities cannot be reset once completed unless the application is restarted.

The second and third activities follow the same structure as the first activity; the only difference is that the second activity focuses more on the law of refraction (see Fig. 3) offering a new refractive cube for the participant to use, and the third activity explores the phenomenon of total internal reflection and provides a more complicated puzzle (see Fig. 4). Once the participant completes the activities, they are assisted in removing the headset and are presented with a survey on a separate device, and all participant responses are self-stored in the survey.

4 Result

Multiple user tests occurred over a three and a half week time span accumulating a total of 16 participants, all being university students. A total of 11 participants were computer science students, while the other 5 were students of different majors, such as physics, mathematics, Design, Chemistry, and Business Management. Due to the small number of participants studying a different major, distinguishing the participants based on major would provide no substantial findings, therefore, all participants are bucketed together. It is also worth mentioning that participants took an average of 30 minutes to complete the application. A total of 5 questions were asked during the post-user testing survey. Questions were on a scale of 1 to 7, asking the participants about their own experience. Although all except for one participant were studying a major other than physics, most participants were familiar with the physics topic of optics. Question 1 asked the participant how familiar they were with the physics topic of optics, where 1 was not familiar and 7 was very familiar. Responses to question 1 found that 14 out of 16 participants reported 4 or higher (see Fig. 5). This suggests that these participants underwent some educational process in the past to obtain their knowledge of optics, even though a majority were studying in majors other than physics.

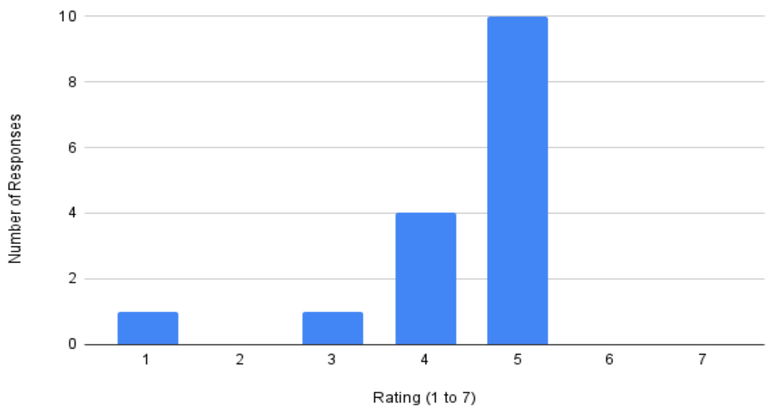

Fig. 5. Results from question 1: Prior to the experiment, how familiar were you with the Physics topic of Optics?

Overall, the user testing was successful, and most participants had a pleasant experience in the optics-based VR laboratory. Question 2 asked the participants how their overall experience was with the application, where 1 was poor and 7 was excellent, receiving an average score of 6 out of 7 (see Fig. 6). The result from question 2 is very favourable, as most participants are not majoring in physics and were still able to have an enjoyable experience exploring the optics-based VR laboratory. Question 3 asked how easy it was for the participant to navigate the VR environment, where 1 was difficult and 7 was very easy, receiving an average score of 5.75 out of 7 (see Fig. 7). Like question 2, question 3 produced a favourable outcome since most individuals had a relatively easy time navigating the VR environment.

The last two questions focused more on the educational content. Question 4 asked how well the optics-based VR laboratory did in exploring the physics topic of optics, where 1 was poor and 7 was excellent, receiving an average score of 5.8 out of 7 (see Fig. 8). This result is favourable as it suggests that the overall design of the application's activities worked well. Question 5 asked the participant how practical the optics-based VR laboratory was in teaching the physics topic of optics in comparison to conventional teaching methods, where 1 was poor and 7 was excellent, receiving an average score of 6.1 out of 7 (see Fig. 9). Although participants were not presented with a conventional means of teaching optics, based on the results of question 1, most participants were familiar with optics prior to the user testing, as well as since all participants are university students, they experience conventional teaching methods quite often. Question 5 produced a favourable outcome as it suggests that the optics-based VR laboratory was perceived to be as practical as conventional teaching methods through the perception of the participants. However, due to the small sample size it is hard to determine if educational VR applications are no more, less, or more effective than regular teaching methods. The results of question 5 are still favorable as it also suggests that university students prefer educational VR applications over conventional teaching methods.

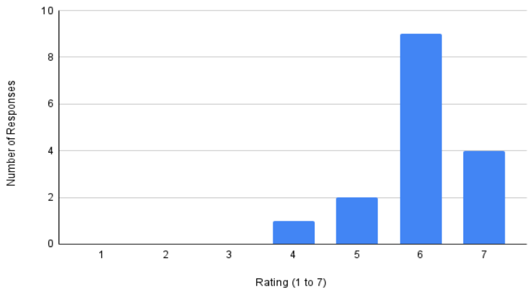

Fig. 6. Results from question 2: Overall how would you rate your experience in the Educational Virtual Reality Application?

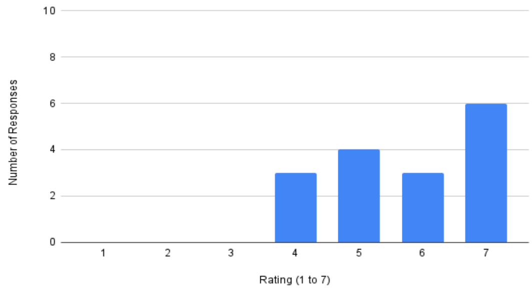

Fig. 7. Results from question 3: Overall how easy was it to navigate the Virtual Reality Application?

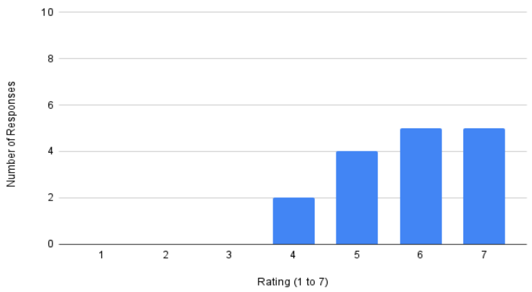

Fig. 8. Results from question 4: Overall how well would you rate the Virtual Reality Application's ability to explore the topic of optics?

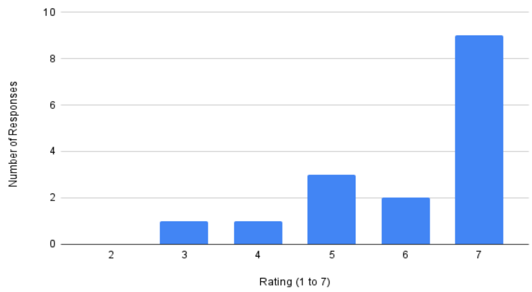

Fig. 9. Results from question 5: Compared to traditional teaching (slides, textbook, etc.) methods you have experienced in the past, how effective was the Virtual Reality Application in teaching the topic of optics?

5 Discussion

The five questions asked during the post-user testing survey provided insights into the optics-based VR laboratory, user experiences and opinions. Question 2 focused mainly on the participant's overall experience, providing a favourable average score. Although most participants were not physics students, the participants were still able to have an enjoyable experience. This could suggest that new teaching methods, such as educational VR applications, may bring enjoyment to learning topics typically not in one's areas of interest. The results from question 2 suggest that the learning theories applied throughout the application may have had a positive effect on the participants.

Further and more comprehensive research is required to validate such suggestions. Question 3 focused on how easy it was to navigate the VR environment, providing positive results. The results from question 3 suggest that the participant had an easy time in the optics-based VR laboratory due to the tutorial area. As mentioned previously, the tutorial area was designed to reduce cognitive overload by allowing participants to get accustomed to the VR experience. The tutorial area would allow each participant to separate learning the controls from learning the material, reducing frustration due to cognitive overload. Question 4 asked how well the topic of optics was explored in the education VR application, providing another positive result. The results of question 4 suggest that the learning theories incorporated in the design and implementation of the activities helped explore the topic better. Question 5 asks how practical the optics-based VR laboratory is in teaching the topic of optics compared to conventional methods, which provided the best result out of all the questions. The results from question 5 suggest that the participants enjoyed learning through the optics-based VR laboratory and suggest that the learning theories applied throughout the application may have aided in user learning. The positive results from the user testing help reinforce the use of the tutorial room, interactive blackboards, puzzles, and the separation between learning and doing. The results also suggest that educational VR applications are potentially effective and helpful to students. Similar designs in separating learning challenges in VR applications pose useful in isolating the core learning content verse learning VR controls. The user study makes it evident that applying learning theories to educational VR applications can provide a positive outcome for the user experience and learning.

A few things were not considered or asked during the post-user testing survey, which should be addressed. One such thing was that individuals could experience motion sickness. It is worth noting that most participants experienced little to no motion sickness, and the ones who did experience it after or at the end of the third activity. Another thing to consider is that VR can be difficult to incorporate into a curriculum as it is not widely used. During the planning phase, the physics domain expert mentioned that the physics lab computers could not support a VR application. Luckily, the optics-based VR laboratory was developed to run natively on Meta Quest 3, but it is worth considering for educators wanting to incorporate VR applications as a teaching tool. However, after completing the research and analysing the results, it is clear that the optics-based VR laboratory holds significant potential to support individuals' learning. The same could be claimed for educational VR applications under a similar investigation. Educators planning on or working with others to develop educational VR applications for their subjects should consider incorporating learning theories, as it has been suggested to be beneficial through the perception of the participants.

6 Future Work

This study has a few practical limitations. Because the work began as a four-month independent research project, the scope and iteration time were necessarily constrained. Participant recruitment was also challenging: the institution has a relatively small pool of physics students, and data collection occurred near the end of term when schedules were less flexible, resulting in a modest sample size.

Future work can build on these results by extending the study timeline, recruiting a more diverse participant pool, and incorporating comparison conditions (e.g., VR-supported learning versus conventional instruction) to examine outcomes such as learning gains and retention. There is also strong potential to expand the application to additional STEM topics (e.g., biology and chemistry) and, over time, evolve toward a broader VR learning platform that supports engaging and accessible discipline-specific experiences.

Looking ahead, 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 perhaps 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

Educational VR applications can provide significant benefits for an individual's education. However, it should be tested to gain insight into the educational VR application's usability and effectiveness to help an individual learn. As discussed in this paper, the user testing done has suggested that the optics-based VR laboratory is potentially effective in teaching optics through the utilization of a tutorial area, interactive blackboards, and puzzle-based structure, while providing a pleasant and easy-to-navigate virtual environment. Incorporating learning theories in educational VR applications can create a fun, yet practical educational experience for students. As more educational VR applications are studied, it creates a bigger appeal to use educational VR applications in the curriculum, which would benefit institutions, educators and students. Investigating educational VR applications can provide a basis to further VR in STEM education, potentially bringing a new type of teaching method to students.

References

1. Di Natale, A. F., Repetto, C., Costantini, G., Riva, G., Bricolo, E., Villani, D.: Learning in the Metaverse: Are University Students Willing to Learn in Immersive Virtual Reality?. Cyberpsychology, Behavior, and Social Networking 27(1), 28-36 (2024).
2. Pirker, J., Holly, M., Gütl, C.: Room scale virtual reality physics education: Use cases for the classroom in 2020 6th International Conference of the Immersive Learning Research Network (iLRN), pp. 242-246. IEEE (2020).
3. Kaufmann, H., & Meyer, B.: Physics Education in Virtual Reality: An Example. Themes in Science and Technology Education 2, 117–130 (2009).

4. Qorbani, S., Dalili, S., Arya, A., Joslin, C.: Assessing Learning in an Immersive Virtual Reality: A Curriculum-Based Experiment in Chemistry Education. Education Sciences 14(5), 476 (2024).
5. Bogusevschi, D., Bratu, M., Ghergulescu, I., Muntean, C. H., Muntean, G. M.: Primary school STEM education: using 3D computer-based virtual reality and experimental laboratory simulation in a physics case study. In Ireland International Conference on Education, IPeTEL workshop, Dublin, Ireland (2018).
6. Zhang, H., Cao, L., Howell, G., Schwartz, D., Peng, C.: An educational virtual reality game for learning historical events. Virtual Reality 27(4), 2895-2909 (2023).
7. Han, U.: Applying Virtual Reality (VR) for Immersive Experiential Learning in Underserved Rural Schools. Immersive Learning Research-Practitioner 9. 103-105 (2023).
8. Lamb, R., Antonenko, P., Etopio, E., Seccia, A.: Comparison of virtual reality and hands on activities in science education via functional near infrared spectroscopy. Computers and Education 124, 14–26 (2018).
9. Sanzana, M. R., Abdulrazic, M. O. M., Wong, J. Y., Ng, K. H., Ghazy, S.: Lecture-based, virtual reality game based and their combination: which is better for higher education?. Journal of Applied Research in Higher Education 14(4), 1286–1302 (2022).
10. Radianti, J., Majchrzak, T.A., Fromm, J., Wohlgenannt, I.: A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & education (147), 103778 (2020).
11. Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H.,Wenderoth, M. P.: Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of sciences 111 (23), 8410–8415 (2014).
12. Korakakis, G., Pavlatou, E. A., Palyvos, J. A., Spyrellis, N.: 3D visualization types in multimedia applications for science learning: A case study for 8th grade students in Greece. Computers & Education 52(2), 390–401 (2009).
13. Webb, J.: Social VR in Education: Transforming Learning Through Immersive Collaboration. Immersive Learning Research-Practitioner 11, 154-157 (2025).
14. Soliman, M., Pesyridis, A., Dalaymani-Zad, D., Gronfula, M. and Kourmpetis, M.: The application of virtual reality in engineering education. Applied Sciences 11(6), 2879 (2021).
15. Lee, S., Jeong, Y., Choe, S., Choi, D. and Ryu, J.: Implementing XR-Based Virtual Science Lab for Inquiry-Based Learning. Immersive Learning Research-Practitioner 11, 89-93 (2025).
16. Shikdar, M., Ahmed, S., Osanapa, D., Ingram, J., Hemraj, S., Selwood, S., Mentzelopoulos, M. and Erenli, K.: Game-based Learning Mars EcoVenture: Rover's Odyssey. Immersive Learning Research-Practitioner 10, 27-31 (2024).