User Movement for Safety Training in a Virtual Chemistry Lab

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Abstract. Virtual Reality (VR) has become a large area of focus especially after the effects of COVID-19. During the lockdown students had to partake in different methods of learning outside of the traditional face-to-face classroom setting. In this paper, we focus on the type of locomotion that students would utilize when traversing in a virtual environment. We studied the effectiveness of two types of movement the first being Embodied Movement, or movement through the Head Mounted Display (HMD) device such as the Oculus Quest, or the HTC VIVE, and the second form of movement being Joystick Movement through the use of a thumb stick on an attached controller. To test these movements, we implemented a scenario in a virtual chemistry lab, where the user's vision is impaired, and they would need to navigate throughout the scene to reach a safety shower that once activated would restore their vision. Our results show that using the joystick controller was more suitable for this type of experiment in terms of user preference and the speed of which the user completed the task. Our results also show that for some subjects when partaking in the study, mild cyber-sickness was prevalent and further investigation is needed on how to mitigate its effects.

Keywords: Virtual Reality, Education, Locomotion.

1 Introduction

In recent years, after overcoming previous restraints, intake on virtual reality (VR) technology has been on a stark rise. However as stated by [1], inconsistencies in implementation of perceived optimal movement strategies have led to mixed insights of the use of VR entirely. Until recently, difficulties in navigation of 3D virtual spaces made 1st person movement to be a high cognitive load task on most systems. This was solved through the discovery that limiting degrees of freedom could increase the performance of system tasks such as visualization and rendering [2, 3]. Results of this discovery led to the formation of three primary forms of movement in VR: Embodied Movement, or the movement being reflected by the user in a confined three-dimensional space into VR, Joystick Movement, or movement using an external controller, and Teleportation which abruptly changes the movement vector of the user to a new point instantaneously.

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Although each movement solution solved the initial problem and gave boon to different benefits, more problems began to arise along with the issue of inconsistency. As stated by Smith and Neff [4] the use of Embodied Movement in virtual reality complimented the nonverbal communication, such as slight head-nods or arm waving, between users alongside that of physical movement. This led to users being able to perform cooperative tasks without the use of verbal communication, such as talking through a microphone. Embodied Movement is also believed to be more natural, as the user is more interactable and has a greater sense of motion when compared to other forms of locomotion [5, 8]. The problem that arose from this method of locomotion was that due to being in a confined space, the area to which the user can move virtually was also confined. As such if the virtual area was not configured to match the specifications of the user's confined space, some parts of the virtual environment would thus be labeled as inaccessible to the user.

Joystick Movement, as expressed by Kison and Hashernian [5], is a more comfortable and precise form of locomotion when compared to other types of virtual movement. As this type of locomotion is more akin to traditional methods of control and movement in virtual spaces, it is easily adaptable, and responsive. When paired with a virtual headset however, a problem that arose was that the user will begin to feel motion sickness when stationary in the real world but moving in VR [6]. Kison and Hashernian [5] believed this problem could be solved by incorporating small physical motions from the user, to help express that movement is occurring.

Teleportation is described by Bozgeyikli and Raij [7] as users simply being able to point where they want to be in the virtual world, and they are teleported to that position. Because this action is instant, motion sickness is reduced as no transition is occurring. The method is not without its challenges as of the three options mentioned, Teleportation gives the user less control, and can lead to issues with collision detection and placing the user out-of-bounds in the virtual environment.

1.1 Virtual Reality Chemistry Lab

The Florida Polytechnic Virtual Reality Chemistry Lab project is a work focusing on providing adaptive remote learning techniques comparable to that of traditional face-to-face learning [9]. Due to prior restrictions from COVID-19 the transition to remote learning has proved to be difficult, but most courses have translated over without any problems. Unfortunately, the same cannot be said for the lab courses, which traditionally have students conduct hands-on experiments. This greatly hampered the instruction of chemistry labs, where students typically conduct experiments using chemicals and instruments. Instead, students watch videos of experiments, write lab reports on provided data, perform at-home experiments, and use virtual simulations [10]. The long-term goal of this work is to develop a complete immersive Virtual Reality (VR) chemistry lab.

In the VR lab space, the student can handle chemicals and equipment to simulate an actual chemistry lab. Using a VR headset and haptic gloves, the user will be able to freely move and interact with the virtual lab, fellow students, and their teacher. Benefits of a virtual lab would also extend beyond the end of the current pandemic. Students who cannot attend lab because they are pregnant, in the military, or are handicapped would benefit from alternative lab experiences that still adequately prepare them for working in a lab [11]. Even before the pandemic began, the utility of undergraduate labs for General Chemistry courses was called into question [10][12][13]. Labs are expensive to conduct [14], and many academic institutions were already experiencing a strained budget. Furthermore, it was questionable if students were actually learning the intended goals [10][12][13].

However, despite the cost and questions about learning, if done correctly, labs can be a vital part of the General Chemistry learning experience. Our solution to remote lab instruction is to use virtual reality (VR) head-mounted displays (HMDs) with haptic gloves. VR is beneficial for student learning for multiple reasons including making abstract ideas seem tangible and making students be actively engaged [15]. Our simulation will allow students to explore a realistic lab setting while handling machinery and chemicals. The haptic gloves will allow the students to feel the weight of the glassware and to handle the lab equipment and chemicals in a safe and controlled manner.

VR has been used in classroom instruction for decades. Computer simulations have been used to augment lab instruction as far back as 1980 [16]. VR-haptic surgery training has been used since 1998 [17][18] and remains an important tool for training doctors and surgeons before practicing on patients. VR has been used to train surgeons in how to do laparoscopies, carotid stenting, and ophthalmology [15]. VR-trained surgeons were 29% faster and six times less likely to make mistakes while performing laparoscopic cholecystectomy gallbladder dissection than surgeons with traditional training [15][19]. These studies show that VR training is effective at preparing doctors. We believe that it can be equally as effective as preparing students for their chemistry courses.

2 Methodology

2.1 Background

This study is intended to evaluate the movement through a learning environment where students can experience classes in a VR setup. The user study tested the two movement types Embodied Movement, and Joystick Movement. Teleportation Movement was excluded from this testing as that mode of movement is designed to traverse large distances and after finding the size of the virtual space being too small for its applicable use. To increase the size of the virtual space would be to lessen the realism the room would hold when comparing the virtual classroom to real world counterparts.

2.2 Application

Our virtual scenario consists of two main components: the HMD and the virtual scene itself. The virtual scene has two capabilities: a classroom and a lab. The HMD used for running our user study was the Oculus Quest 2 tethered to a Personal Computer using the Oculus Link Cable. For a realistic rendering of the scene, we used High-Definition Render Pipeline and Physically based Rendering (PBR) [24, 25] in the Unity Game Engine using the HurricaneVR software package. PBR uses bi-directional reflectance distribution function (BRDF) [26, 27] to approximate accurate light-flow models. We placed an interactive menu on the wall in our scene that would act to begin the scenario.

Fig. 1. View of the interactive menu in the virtual scene

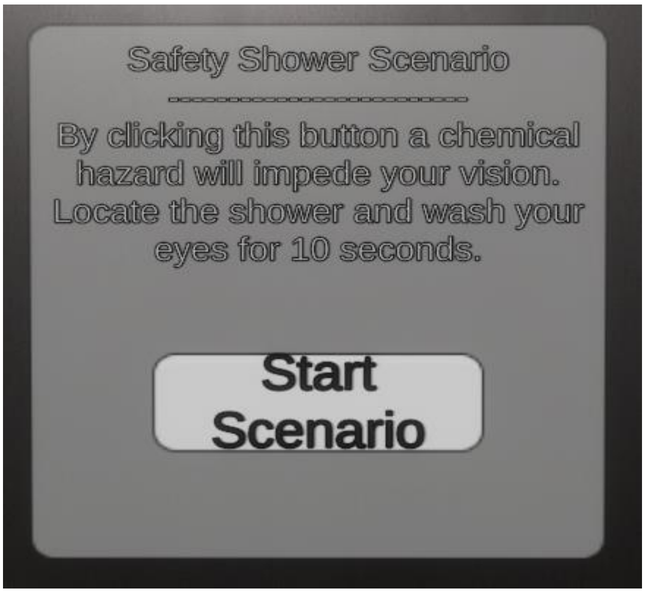


Fig. 2. A close-up of the interactive menu inside the virtual scene that users will use to begin the scenario

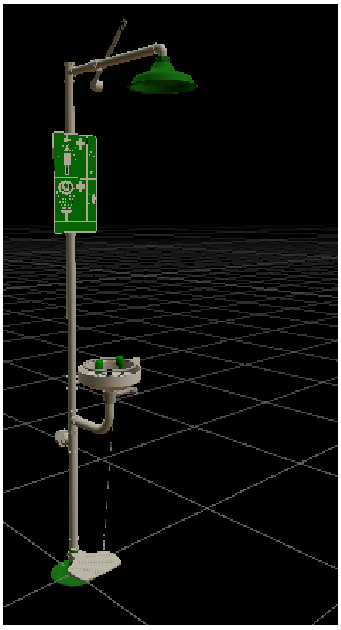


Fig. 3. The model of the safety shower used in the virtual scene

Before we begin the testing scenario, we had the user get acquainted to the virtual scene and the different movement types by freely traversing the scene and discovering the VR chemistry lab. They took as much time as needed. Once the scenario begins all, but one safety shower on the other side of the scene is disabled, and a volume box is enabled that would impair the vision of the user by adjusting the color and adding a film grain, vignette, and motion blur to the camera. Once the vision is impaired the user will try to navigate to the safety shower and pull a lever to activate it. Once the shower is activated the user must stand underneath it and not move for ten seconds for their vision to be repaired. If the user were to move out of the zone of the safety shower, they must repeat the process of pulling the lever and standing underneath the shower again. This process of starting the scenario and navigating to the safety shower is repeated four more; two times using just embodied movement and two times using joystick movement only, the order of which was randomized to each user. As a way to measure the effectiveness of each trial, we recorded how long it would take the user to complete the task, relating how fast the trial took to how comfortable the movement type was to the user.

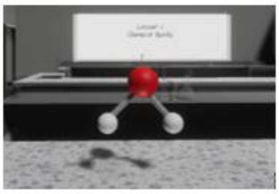
Fig. 4. Version of the scene with the impaired vision

2.3 Questionnaire

The questionnaire began by giving the user a general description on what the user would be experiencing in this virtual scenario. This was followed by a pre-questionnaire about the user's background in chemistry and experience with using a VR headset. The background questionnaire consists of simple multiple-choice questions (as seen in Figure 5) followed by questions about the user's demographic data such as the user's department of study. The questions comprise of understanding the user's VR knowledge, and experience in chemical lab safety procedures.

Usability Study – Virtual Reality Learning Framework

This user study is intended to evaluate the movement through a learning environment where students can experience classes in a virtual reality (VR) setup. We will be testing two movement types in VR, the first being Lean-In / Head Mounted Display (HMD) movement where the movement from the VR headset is translated to movement in the Virtual World, and the second being Joystick movement with a controller.



This study aims to evaluate the vision, and movement of the user where visibility will be impaired, and the user will navigate to the safety shower in order to clear their eyesight.

PRE- Background Questions

Q1- Do you have any Virtual Reality Experience:

a) Experienced VR user
b) Moderate Experienced
c) I have tried it a few times
d) Novice to VR

Q2- Have you taken a chemistry course in either high school or college:

a) Yes
b) No

Q3- Do you have any experience with lab safety procedures:

a) Experienced
b) Moderate experience
c) Never been taught

Do you have any experience in VR education (yes/no)? If yes, please explain:

In which department/area is your field of study/work:

Fig. 5. The Pre-Questionnaire given to the users partaking in the study

After partaking in the scenario, the users were given a post-evaluation questionnaire with open-ended and Likert-like questions which outlined how the user's experience was using the two different types of movement being studied in VR. The Likert-like questions for the post-evaluation asked the user about their comfortability using embodied movement and joystick movement while running the scenario. The open-ended questions focused on if the user felt any nausea or dizziness while performing the tasks and asked about their opinions regarding the experiment.

POST – Evaluation

What is your preferred movement in VR:

a) Head Mounted Display / Lean In
b) Joystick
c) Depends on the task

Explain:

How difficult was it to navigate using the Head Mounted Display?

(Easy) (Hard)

1 2 3 4 5

How difficult was it to navigate using the Joystick?

(Easy) (Hard)

1 2 3 4 5

How difficult was it to locate the showers with impaired vision using the Head Mounted Display?

(Easy) (Hard)

1 2 3 4 5

How difficult was it to locate the showers with impaired vision using the Joystick?

(Easy) (Hard)

1 2 3 4 5

How was your experience performing this experiment?

(Bad) (Great)

1 2 3 4 5

Did you experience any form of dizziness or nausea while performing the tasks? (Please explain your answer):

If so, what type of movement caused this?

Do you expect VR classes to become available in the future? (Please explain your answer):

Did you find any positive/negative experiences while doing the tasks?

Any additional comments for improvement?

Fig. 6. The Post-Evaluation Questionnaire given to the users after the study

3 Results

Seven participants performed the experiment: six males and one female. All the subjects are students at Florida Polytechnic University. The participants are between the ages of 18 and 24. Regarding the multiple-choice questions of the pre-background questionnaire, when asked if they had prior experience regarding Virtual Reality, six of the seven answered “I have tried it a few times” with the remaining student being a “novice to VR." All students participating had previously taken a chemistry course, with four students being experienced in lab safety procedures, and three students having some moderate experience regarding lab safety. When asked if the participants had any education in VR such as taking a course or having VR incorporated into a previous subject two of the seven students expressed "yes" they had, while the remaining five did not. Out of the seven students five students belonged to the Computer Science department of Florida Polytechnic University, one was part of the Mechanical Engineering department, and the final student belonged to Analytics and Logistics.

Five of the subjects did complete the experiment fully while the other two did not complete it for the following reasons. One subject (female) experience Virtual Reality induced symptoms in the form of nausea and we had to stop the experiment. The other person was not able to complete the experiment because of technical issues where the Quest 2 room guardian settings, in the form of a virtual border that prevents the user from colliding with real life obstacles, prevented the subject's ability to reach and grasp the shower head. Thus, for that subject we only recorded the joystick results. For the remaining subjects we have disabled the guardian settings and we kept an eye on their movement in case they got close to an obstacle.

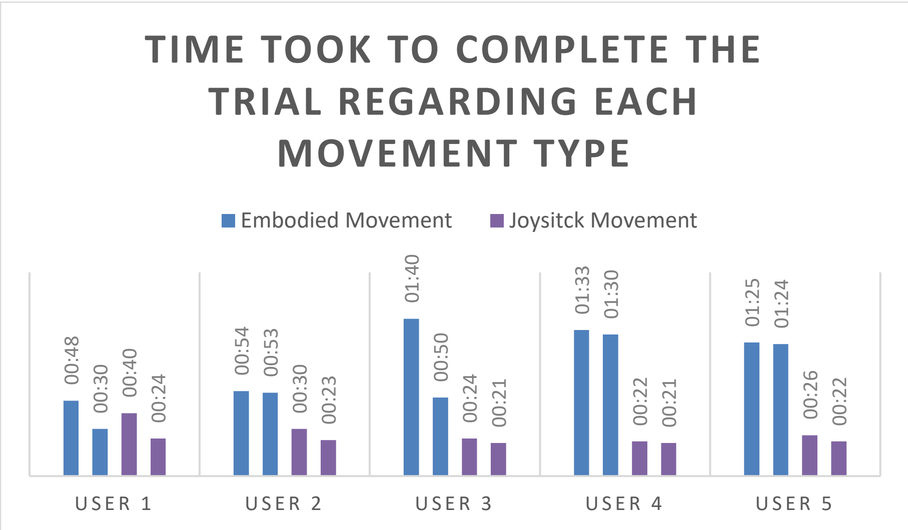


Fig. 7. Comparison of movement types to time took to complete

The results from Figure 7 are from the five students who were able to complete the scenario. Across all users the time it took to complete the scenario with regards to a particular movement type have remained consistent with the second trial of both Embodied Movement, and Joystick Movement being faster than the first. Due to this fact, we could assume that the randomization of the shower's location did not affect the speed it took to complete the trials. The results also show that movement using the Joystick is significantly faster than movement with the HMD.

During the post-scenario questionnaire, six of the seven students agreed that navigating with the joystick was easier to perform than using Embodied Movement and everyone agreed that although their vision was impaired it was easy to locate the safety showers. Three of the seven students had some form of dizziness or nausea from partaking in the scenario one student when moving with the joystick, another when using Embodied Movement, and the last student expressed getting dizzy when using both movement types. Regarding the open questioned portion of the questionnaire all students agreed they can expect VR to be used in classes to some degree in the future.

A common issue that was expressed was the complications students had when partaken in the scenario using embodied movement due to the tethering of the headset to the PC. Due to the cable's length, students' movement were heavily restricted, and as such additional time was needed to reposition.

4 Conclusion

In this paper we presented two ways of moving users in a virtual lab. The first being Embodied Movement through the use of an HMD, for our purposes we used the Oculus Quest 2, and the second type being Joystick Movement where locomotion is controlled in part by a thumb stick on the controller. We also performed this user study to evaluate the speed it would take the user to complete the scenario, and their preferred method of movement. We also took in to account any cyber-sickness such as dizziness or nausea when partaking in activities related to VR.

For our safety training scenario, the preferred method of locomotion was the use of Joystick Movement. This was evident to the user's responses to the post-scenario questionnaire where we asked the user how difficult using each type of locomotion was, and their experience participating in the scenario. This could also contribute to the user's speed of completion in relation to the type of movement being tasked for the users that completed the experiment.

For future trials, work will be done into untethering the HMD from the PC, such as using the Oculus Quest's AirLink feature in order to better enhanced the experience of the user using Embodied Movement and negate any complications with restricting the user movement. Untethering the PC will also enhance the VR learning experience by having a more life-like interpretation where actions could be incorporated to real world use. The only setback is that not every headset has this option, and to be more universal tethering options would always be accounted for when working with VR.

In addition, we would like to implement Teleportation Movement for rooms of greater size in order to traverse larger distances. Due to the area utilized for chemistry labs and the tight spaces between equipment teleportation may not be effective but is something we would be willing to test. Furthermore, we want to further investigate the effects of cyber-sickness on the user, and how it relates to the movement being done in our virtual scene.

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