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Improving Accessibility of Elevation Control in an Immersive Virtual Environment

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***Abstract*- Despite the advances made in Virtual Reality (VR) technology, the design of VR experiences lacks sufficient focus on accessibility and inclusion as the primary requirements. These are especially important for STEM education, where engaging in experiential activities is essential. This study was conducted to investigate accessibility considerations in the design and development of Immersive VR (IVR) learning spaces for wheelchair users. The specific research question is: How can we make a VR system easier to interact with for wheelchair users needing vertical movement? A user study with thirty (30) participants in three groups was conducted: Group A (the control group, non-wheelchair users) who used natural body movement to interact with the environment, Group B (verification group, non-wheelchair users) who used software controls for accessibility, and Group C (wheelchair users) who used the same software accessibility feature. The results indicate that the accessibility feature enabled wheelchair users to complete the tasks requiring raising or lowering of the body, with almost similar levels of completion rate and accuracy.**

Keywords: Virtual Reality, Learning, VR Accessibility, Human-centered computing

I. Introduction

Virtual Reality (VR) and Augmented Reality (AR) technologies are becoming more affordable and available due to the advancement of these technologies in recent years. VR can be highly interactive and engaging, improve users' task completion rate and facilitate the learning process [1][2][3].

Most virtual environments offer the potential to reduce the limitations of a physical structure as they can be configured and use different control mechanisms. However, this potential has not been sufficiently investigated when it relates to accessibility. VR features such as "guardian" (i.e., a safe movement box around the user) may not be appropriate for those using a wheelchair who cannot maneuver in such a limited space.

Virtual Reality (VR) is a technology that allows users to interact with a computer-simulated environment. It can be based on an entirely imaginary world or the real one where users can go to virtual places or do the things that are usually challenging for them. Simulation and visual realism provide great potential for training opportunities that are very close to reality allowing users to practice with systems leading to reducing costs and risks. Sufficient practice in VR will enable learners to develop needed skills and gain experience and confidence to work in actual conditions with real equipment.

Accessibility issues in VR and AR were identified as a noticeable study gap in several literature reviews over the past decade [4] [5][6] [7]. As the population of people with a disability grows [8][9][10], there is a very limited pool of research addressing barriers for students with disabilities in science laboratories, or best practices for facilitating accessibility in the laboratory environment [11]. Efforts for creating VR experiences that are accessible to a wider range of users (especially wheelchair users) seem to be too slow, as reviewed in Section 2. For example, safe zones of movement for headset-based VR experiences can be small and uncomfortable for wheelchair users. Similarly, reaching higher or lower points in the VR environment to grab and manipulate objects can be difficult for these users. As a result, people with such disabilities are unable to use VR systems effectively, even though the programmable nature of VR and other digital environments promises more accessibility than the physical world.

The study reported in this paper investigates how to facilitate vertical movement in a VR environment for wheelchair users. While various forms of customization of the environment could be considered, we focus on software controls to increase and decrease the user's virtual elevation. We hypothesize that this allows a simple yet effective way to use the same virtual environment as non-wheelchair users with minimum customization effort.

The result of this study can contribute to creating more accessible VR experiences for wheelchair users. Increased accessibility can help this group of users to complete tasks more efficiently when compared to non-wheelchair users. Potential for further improvements include other accessibility mechanisms and also the use of artificial intelligence (AI) tools to understand users' needs and offer dynamic environments with personalized accessibility measures.

It is worth mentioning that without the accessibility feature allowing users to change their virtual height, wheelchair users in this study would not be able to complete certain tasks that would require raising or lowering the body to reach an object. The same access limitation exists in the real world for wheelchair users, where lab equipment can be

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out of reach, particularly in the labs that are not modified or enhanced for such users.

II. Related Work

The United Nations defines disability as a constraint or deficiency of the ability to carry out an activity as a normal healthy human being [11][12]. Disabilities can be divided into main types: Mobility/Physical, Spinal Cord (SCI), Head Injuries (TBI), Vision, Hearing, Cognitive/Learning, Psychological, and Invisible disabilities [13][14][15]. In 2017, one in five (22%) of the Canadian population aged 15 years and over – or about 6.2 million individuals – had one or more disabilities [9].

On the other hand, the physical structures in most science laboratories are unwelcoming to people with physical disabilities and wheelchair users, or it is mostly inaccessible [16]. Doors, workbenches, sinks, fume hoods, and cabinets are examples of what cause accessibility issues related to vertical and horizontal movement to access different objects.

In this study, we focus on only a type of physical disability that requires the use of a wheelchair. Such use limits the user's vertical movement due to the constant sitting position they must assume during normal activities.

A useful characteristic of VR, as mentioned by Wilson, Foreman & Stanton [17], is that the need for semantics, symbols, or language in VR is virtually eliminated due to the experiential nature of the learning process, which allows many users from different ages and countries to enjoy using it. VR can play the role of "assistive technology" as well. Lewis [10] hypothesized assistive technology as having two objectives: (1) to enhance a person's strengths to overcome the impacts of disability, and (2) another way to complete a mission that compensates for a disability.

Six key areas of accessibility to be considered by the Universal Design and VR community [18][19] are defined as:

1. Accessibility of interaction techniques
2. Accessibility of VR content
3. Device/hardware accessibility
4. Inclusive user representations within VR
5. Environments
6. Accessibility-focused applications for VR

"SeeingVR" [28] is a set of tools to make VR more accessible to people with low vision, and "Virtual Reality Without Vision" [29] is another recent experiment to make VR accessible for people with vision impairments.

Other studies related to people with physical disabilities were focused on handheld controllers and eye-tracking [30] [7], indicating that controlling devices should be simple and uncomplicated. There are limited studies to address wheelchair users' accessibility issues in VR. Therefore, we have focused on the accessibility of VR content, interaction, and its effects on performance and learning.

III. Research Approach

A. Overview

To address some of the identified gaps, this study was designed to compare wheelchair users with non-wheelchair users in a virtual lab. The aim was to investigate if using software controls can offer accessibility and learning advantages to wheelchair users in VR. By completing this study, we were able to compare and validate what kind of accessibility feature(s) could be developed to help wheelchair users access virtual objects in an IVR environment. Two types of elevation change features were designed and developed to test three groups of users:

- Group A (control group, non-wheelchair users), using body movement.
- Group B (verification group, non-wheelchair users), using software controls for accessibility.
- Group C (target group, wheelchair users), using software controls for accessibility.

We defined two research questions:

- RQ1: Can software controls for vertical movement provide improved accessibility for wheelchair users with task efficiency and completion rate similar to non-wheelchair users?
- RQ2: Can the improved accessibility (if any) improve learning?

To investigate and answer these questions, we developed a chemistry curriculum-based activity (i.e., setting up a chemistry experiment in a fume hood). Our proposed experiment is designed to show a chemistry lab simulation within two areas (a tutorial area and the main lab area):

Area 1- A tutorial activity space to help participants use handheld controllers to interact with objects.

Area 2 – The main lab area (shown in Figure 1) with a chemistry station (fume hood) where all users (see below) will be asked to complete the activity.

Fig. 1. Area 2, the main virtual lab.

B. Participants

Participants were undergraduate university or college students in Science or Engineering programs. The inclusion criteria were that participants should be able to use the Internet and be willing to use a VR headset (no previous experience was required). Three groups of non-wheelchair users and wheelchair users with two conditions (using the accessibility feature for wheelchair users, and not using the accessibility feature for the control group) were recruited based on a gender-balanced participants group. The verifying group was asked to use the accessibility feature for comparison with actual wheelchair users who have been using wheelchairs and scooters.

We collected objective data using the in-app data collection system to record completion time, success rate, and accuracy. For the subjective data, we used an online survey to measure usability and learning.

We had ten (10) participants in each group. Groups B and C could access to height changing feature by pressing the X button on the left-hand controller (Figure 2.) It featured two types of UI elements to help users adjust their height and increase or decrease access elevation. Using the Up/Down button would change the height in 20-centimeter increments, while the Slider feature would change the height in a smooth manner controlled by a visible laser beam emitting from handheld controllers known as "ray-casting".

This study was approved by the institutional Ethics Board and was conducted online with downloaded programs for VR headsets.

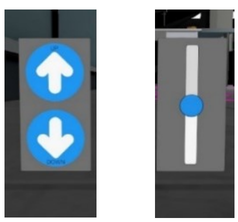


Fig. 2. The "UP/Down" and "Slider" accessibility features

C. Materials

We used the following Hardware/Software to build the experiment and conduct user testing: Head Mounted Display (HMD), Oculus Quest headset, 6 Degree of Freedom (DoF) (with double handheld controller). Display resolution: 1440 x 1600 per eye, 72Hz refresh rate. A personal computer, OptiPlex 980 Tower, Core i7-860 2.8GHz, 16GB RAM, 2TB HDD, and a monitor.

The VR experiment was developed using Unity 3D game engine2019.3.0 plus the latest oculus Integration Software Development Kit (SDK). All the objects and assets were either modeled using 3DS Max software (where each object was exported into FBX format and imported into Unity) or acquired through the Unity asset store. We used the Oculus Integration software development kit (SDK) for adding interactions.

D. Procedure

The experiment for each group has two parts: (1) completing a list of tasks shown and narrated to them in the VR environment, and (2) completing a post-experiment online survey.

This VR experiment was built based on real-world interactions for selecting and picking up objects in a virtual chemistry lab placed at different elevations. Participants were asked to complete the tasks by lowering and raising their hands/arms and body to reach objects.

We collated objective data related to task efficiency and completion rate using the in-app data collection system developed by the researcher for this study. This system would record the type and duration of each interaction initiated by users while interacting with virtual objects and the environment. For task efficiency and accuracy, we used the logged data generated by the above-mentioned system, which included:

- Player's position and orientation (including body, head, and hand)
- Session start/finish time and calculated the duration
- Timestamp and duration of each interaction with objects both using raycaster and/or hands.

This feature eliminated errors in data collection and did not interrupt the user testing process as participants did not experience any intermittent distraction to answer a question during the experiment. The collected data was automatically sent to a dedicated email address made for this study when participants completed the VR experience. Participants were asked to complete a usability survey based on 5 points Likert scale that included (i) how pleasant the activity was (ii) how easy the task was to perform (iii) how easy it was to learn the task.

Participants were guided through in-app instructions in the form of narration and interactive text to perform two activities (setting up two chemistry experiments). We use the term “activity” to refer to a set of “tasks” listed below:

- Locating objects: By looking around the environment and locating objects in response to the task description provided to them in pop-up windows.
- Highlighting: highlighting an interactable object using a laser beam (i.e raycast) to point towards the object (Figure 3).

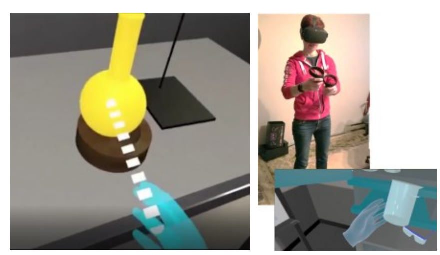


Fig. 3. A highlighted round flask. The dotted line represents a ray cast

- Grasping: virtually picking up an object using the handheld controller and its "Grip" button. Releasing the grip/mouse button results in the virtual object falling, or being placed at any location chosen by the participant
- Releasing/docking: After grasping an object, the user will move it to a target area and release it at that place. For example, attaching a flask to a tripod.

- Manipulating: Mainly involves pressing a button to interact with menu items and dialog boxes.
- Traveling/teleporting: this is mainly for horizontal and/or precise movement by using the controller buttons (for larger distances), or for physical movement such as walking inside the pre-define safe area (shorter distances) or using the joystick movement to travel. Users were cautioned about using this feature as it could induce cybersickness in some users (3% of users in our case had a mild level of cybersickness).

For the highlighting and grasping tasks, some of the interactable objects were placed at different elevations. For example, a piece of equipment was placed on the top shelf requiring the user to reach up, or a flask was placed inside a desk drawer that required the user to bend down to open the drawer and pick it up. Figure 4 a-b shows the wheelchair user's eye-level view in VR space.

(a) User wears the VR headset and starts the VR experience

(b) User follows instructions to set up an experiment

Fig. 4. Wheelchair user's eye-level view

IV. RESULTS

A. *Demographic information*

In total, 30 responses were recorded in the survey, which was made up of three groups of equal participants. 53% were females and 47% were males. Most of the participants (83%) were right-handed. The average age of participants was 24.5, with the youngest participant being 16 and the oldest participant being 43. In group C (wheelchair users), we had eight participants (5M, 3F) who were actual wheelchair users and used a wheelchair due to mobility issues. One participant (M) was a temporary wheelchair user, and one (F) was a roleplaying wheelchair user who could not complete the experiment due to cyber sickness, therefore it was discarded.

All three groups mentioned VR games, popular 360-degree VR videos, and similar forms of experiences using lower-end VR devices such as VR cardboard.

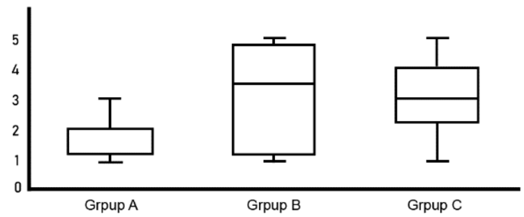
B. *Tasks that did not require lowering/raising the body*

Tasks that didn't need vertical body movement were designed to establish a baseline which helped us understand if there are any differences in the three groups of participants. To ascertain the perception of participants on VR tasks that did not require raising or lowering of the body, we asked:

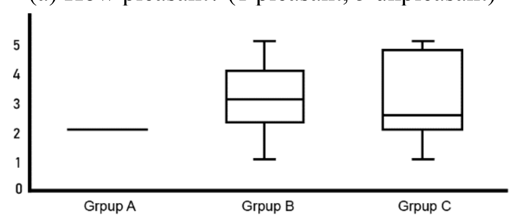
(i) How pleasant was the activity?
(ii) How easy was it to perform the activity?
(iii) How easy was it to learn the activity?

Different statistical methods were used to analyze the data. For example, ANOVA is a method to separate data into different components. A one-way ANOVA is used in similar cases when we have three or more groups.

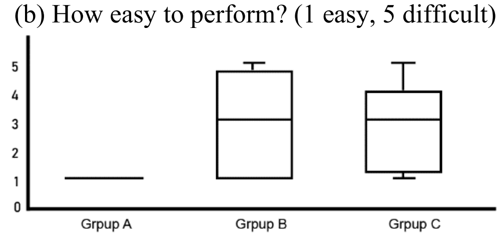
A Shapiro-Wilk normality test [32] (SW) was carried out to verify the parametric assumptions that the data are normally distributed ($p < 0.05$). Based on the results, it was noted that the data from the survey did not follow a normal distribution (Figure 5 a-c). Thus, a non-parametric test was favored. Non- parametric methods are used when data doesn't have a normal distribution or when we are using ordinal data such as the Likert scale and non-numeric labels. Given the fact that we have 3 groups, and the aim is to assess the differences in each, the Kruskal-Wallis (KW) non-parametric test was selected to help determine the distribution differences. KW test is the non-parametric analog of a one-way ANOVA, which does not make assumptions about normality [33].



(a) How pleasant? (1 pleasant, 5 unpleasant)



(b) How easy to perform? (1 easy, 5 difficult)



(c) How easy to learn? (1 easy, 5 difficult)

Fig. 5. Distribution of responses for tasks that did not require lowering or raising the body. (a) How pleasant, (b) How easy to perform, (c) How easy to learn

From the output of the analysis (Table 1), it was noted that for the question "How pleasant the activity was" and "How easy it was to perform the task", there is no significant difference in the distribution of responses ($p > 0.05$). However, for the question "How easy it was to learn the task", the distribution of the data was noted to be significantly different ($p < 0.05$) between the three different groups. Further enquiries were carried out to ascertain where these differences occur, using a post hoc test [34]. It was noted that Group A's responses were significantly different ($p < 0.05$) from Group B and C.

While Group B and C had no significant difference in distribution. This indicates that Group A has significantly more individuals who agree with the statement that learning tasks that did not require body movement were easy.

TABLE I. SUMMARY FOR TASKS THAT DID NOT REQUIRE LOWERING/RAISING OF THE BODY BETWEEN GROUPS

How pleasant was the activity? (1 pleasant,5 unpleasant)			
Scale	Group A	Group B	Group C
1	16.67 %	9.68 %	10.13 %
2	66.67 %	6.45 %	20.25 %
3	16.67 %	9.68 %	18.99 %
4	-	25.81 %	25.32 %
5	-	48.39 %	25.32 %
How easy was it to perform the activity? (1 easy, 5 difficult)			
1		3.13 %	6.67 %
2	85.71 %	12.50 %	20.00 %
3	14.29 %	28.13 %	10.00 %
4	-	25.00 %	13.33 %
5	-	31.25 %	50.00 %
How easy was it to learn the activity? (1 easy, 5 difficult)			
1	81.82 %	13.79 %	10.34 %
2	18.18 %	6.90 %	13.79 %
3	-	-	-
4	-	27.59 %	41.38 %
5	-	51.72 %	34.48

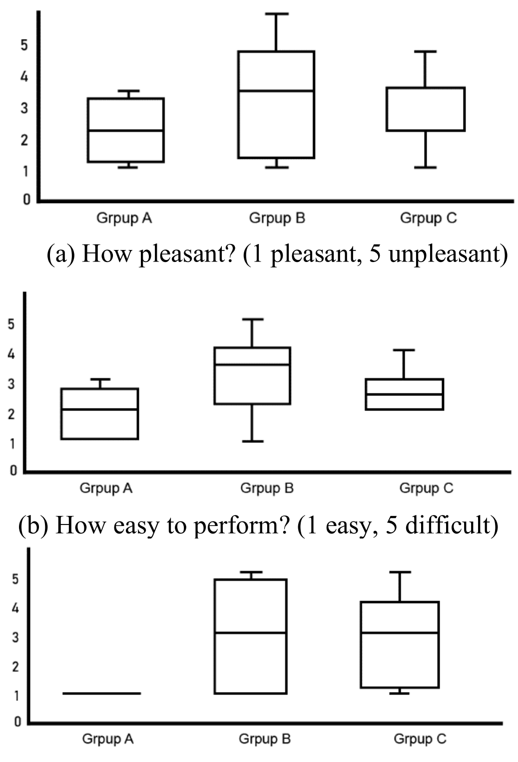
C. *Tasks that required lowering the body*

To ascertain the perception of participants on VR tasks that required lowering the body, we asked the same three questions as in section 4.2. (Figure 6 a-c).

The normality of the data was assessed using the Shapiro-Wilk normality test, due to the small sample size. The results showed that the data is not normally distributed ($p < 0.05$), indicating that the responses have violated the assumptions for a parametric test, and therefore, the KW test was utilized to assess the group differences. This analysis helped to assess the mean rank differences.

For the question "How pleasant was the activity?" and "How easy it was to learn the activity?", there is no significant difference in the mean rank for the distribution of responses ($p > 0.05$). For the question of "How easy it was to perform the activity?", the distribution was noted to be significantly different between the groups. A post hoc test was conducted, and the results indicated that Group C's responses were significantly different ($p < 0.05$) from A and B.

While Groups A and B showed no significant difference ($P > 0.05$) in distribution group A has significantly more individuals who agree with the statement that learning the activity that require lowering of the body were easy (Table 2). In this section, the differences in the mean rank of the responses were assessed for the task that required lowering the body, using a Mann-Whitney U test and provided the comparison of the two groups. From the result, it was noted that there is no critical distinction ($p > 0.05$) in the mean rank between experienced and non-experienced members.



(a) How pleasant? (1 pleasant, 5 unpleasant)

(b) How easy to perform? (1 easy, 5 difficult)

(c) How easy to learn? (1 easy, 5 difficult)

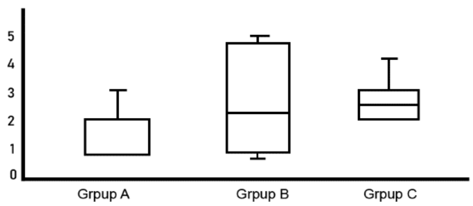
Fig. 6. Distribution of responses for the activity that required lowering the body. (a) How pleasant, (b) How easy to perform, (c) How easy to learn

TABLE II. SUMMARY FOR TASKS THAT REQUIRE LOWERING OF THE BODY BETWEEN GROUPS

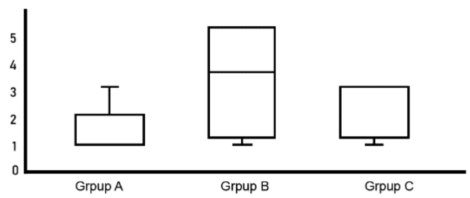
How pleasant was the activity? (1 pleasant,5 unpleasant)			
Scale	Group A	Group B	Group C
1	15.00 %	10.34 %	3.57 %
2	40.00 %	13.79 %	21.43 %
3	45.00 %	-	42.86 %
4	-	41.38 %	14.29 %
5	-	34.48 %	17.86 %
How easy was it to perform the activity? (1 easy, 5 difficult)			
1	21.05 %	3.03 %	-
2	31.58 %	12.12 %	35.71 %
3	47.37 %	18.18 %	32.14 %
4	-	36.36 %	14.29 %
5	-	30.30 %	17.86 %
How easy was it to learn the activity? (1 easy, 5 difficult)			
1	66.67 %	14.81 %	25.00 %
2	33.33 %	7.41 %	20.00 %
3	-	11.11 %	30.00 %
4	-	29.63 %	-
5	-	37.04 %	25.00 %

D. *Tasks that required raising the body*

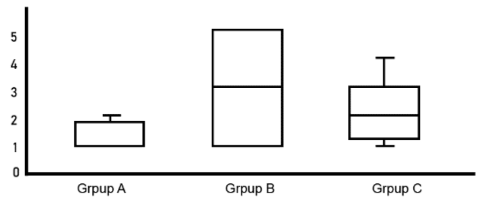
To ascertain the perception of participants on VR tasks that required raising the body, we asked the same three questions as in section 4.2. (Figure 7 a-c).



(a) How pleasant? (1 pleasant, 5 unpleasant)



(b) How easy to perform? (1 easy, 5 difficult)



(c) How easy to learn? (1 easy, 5 difficult)

Fig. 7. Distribution of responses for the section of a task requiring raising of the body. (a) How pleasant, (b) How easy to perform, (c) How easy to learn

The results from the normality tests showed that the data is not normally distributed ($p < 0.05$), indicating that the responses have violated the assumptions for a parametric test. The KW test was selected to analyze the data. This analysis helped to assess the mean rank differences. From the output of the analysis (Table 3), it was recorded that for the question "How pleasant was the activity?", "How easy it was to perform the activity" and "How easy was it to learn the activity?", there is no significant difference in the mean rank for the distribution of responses ($p > 0.05$).

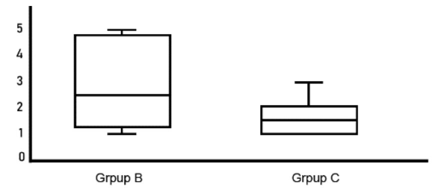
TABLE III. SUMMARY FOR TASKS THAT REQUIRE RAISING OF THE BODY BETWEEN GROUPS

How pleasant was the activity? (1 pleasant,5 unpleasant)			
Scale	Group A	Group B	Group C
1	21.05 %	10.34 %	-
2	42.11 %	13.79 %	35.71 %
3	15.79 %	10.34 %	32.14 %
4	21.05 %	13.79 %	14.29 %
5	-	51.72 %	17.86 %
How easy was it to perform the activity? (1 easy, 5 difficult)			
1	22.22 %	9.38 %	13.04 %
2	44.44 %	6.25 %	8.70 %
3	33.33 %	9.38 %	78.26 %
4	-	12.50 %	-
5	-	62.50 %	-
How easy was it to learn the activity? (1 easy, 5 difficult)			
1	53.85 %	16.67 %	13.04 %
2	46.15 %	-	26.09 %
3	-	-	26.09 %
4	-	-	34.78 %
5	-	83.33 %	-

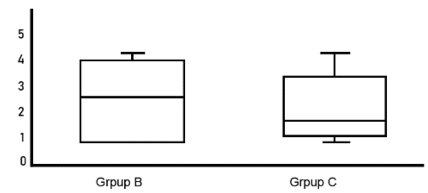
The differences in the mean rank of the responses for the task that required raising of the body were assessed using a Mann- Whitney-U test to provide comparisons between the two groups. From the result, it was noted that there is no critical distinction ($p > 0.05$) in the mean rank between experienced and non-experienced members.

E. Accessibility "Up/Down" button

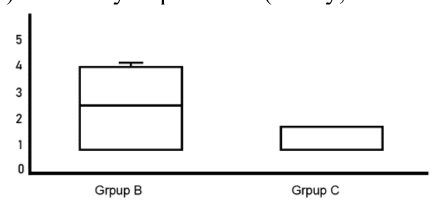
To ascertain the perception of participants of groups B and C participants on the accessibility feature for adjusting the height/elevation using the up/down buttons, we asked the same three (3) questions. (Figure 8 a-c).



(a) How pleasant? (1 pleasant, 5 unpleasant)



(b) How easy to perform? (1 easy, 5 difficult)



(c) How easy to learn? (1 easy, 5 difficult)

Fig. 8. (Distribution of responses for groups B and C on accessibility buttons. (a) How pleasant, (b) How easy to perform, (c) How easy to learn

The results from the normality tests showed that the data is not normally distributed ($p < 0.05$), indicating that the responses have violated the assumptions for a parametric test. The Mann- Whitney U test was selected to analyze this data to assess the mean rank differences.

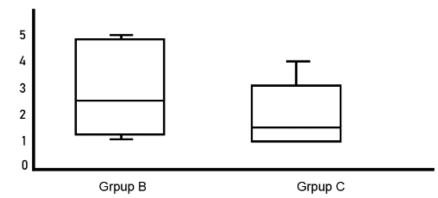
From the output of the analysis (Table 4), it was recorded that for the question "How pleasant was the activity?", "How easy was it to perform the activity?" and "How easy was it to learn the activity? ", there is no significant difference in the mean rank for the distribution of responses ($p > 0.05$).

TABLE IV. SUMMARY FOR THE RESPONSES FOR GROUPS B AND C ON THE ACCESSIBILITY BUTTON

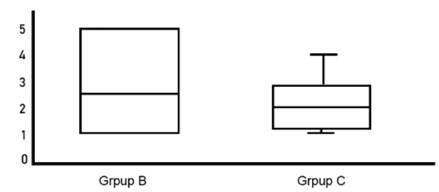
How pleasant was the activity? (1 pleasant,5 unpleasant)		
Scale	Group B	Group C
1	10.34 %	27.78 %
2	13.79 %	33.33 %
3	10.34 %	16.67 %
4	13.79 %	22.22 %
5	51.72 %	-
How easy was it to perform the activity? (1 easy, 5 difficult)		
1	13.79 %	11.54 %
2	6.90 %	23.08 %
3	-	-
4	27.59 %	46.15 %
5	51.72 %	19.23 %
How easy was it to learn the activity? (1 easy, 5 difficult)		
1	13.79 %	26.32 %
2	6.90 %	21.05 %
3	-	-
4	27.59 %	-
5	51.72 %	52.63

F. *Accessibility "Slider" feature*

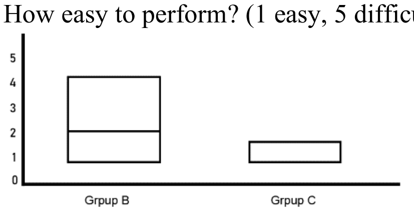
To ascertain the perception of participants of Group B and Group C participants on the accessibility feature for adjusting the height/elevation using the slider feature, we asked the same three (3) questions. (Figure 9 a-c).



(a) How pleasant? (1 pleasant, 5 unpleasant)



(b) How easy to perform? (1 easy, 5 difficult)



(c) How easy to learn? (1 easy, 5 difficult)

Fig. 9. Distribution of responses for groups B and C on accessibility "Slider" feature. (a) How pleasant, (b) How easy to perform, (c) How easy to learn

The results from the normality tests showed that the data is not normally distributed ($p < 0.05$), indicating that the responses have violated the assumptions for a parametric test. The Mann- Whitney U test was selected since there were only two groups presented. This analysis helped to assess the mean rank differences. From the output of the analysis (Table 5), there is no significant difference in the mean rank for the distribution of responses on three questions.

TABLE V. SUMMARY FOR THE RESPONSES FOR GROUPS B AND C ON THE ACCESSIBILITY SLIDER FEATURE

How pleasant was the activity? (1 pleasant,5 unpleasant)		
Scale	Group B	Group C
1	10.34 %	25.00 %
2	13.79 %	10.00 %
3	10.34 %	45.00 %
4	13.79 %	20.00 %
5	51.72 %	-
How easy was it to perform the activity? (1 easy, 5 difficult)		
1	13.79 %	14.29 %
2	6.90 %	38.10 %
3	10.34 %	28.57 %
4	-	19.05 %
5	68.97 %	-
How easy was it to learn the activity? (1 easy, 5 difficult)		
1	17.24 %	22.22 %
2	-	55.56 %
3	-	-
4	13.79 %	22.22 %
5	68.97 %	-

G. *In-App Data (Efficiency/ Task completion rates/ Accuracy)*

As explained in Section 3.4, the in-app data collecting system was used to track and record users' paths and interactions with the environment and virtual objects. This feature allowed us to measure users' performance, completion rate, and accuracy of each task. The interaction data on the device was sent to the researcher's email upon the completion of the VR experiment with a unique ID generated automatically by the app. Participants would use this ID to complete a post-experiment survey to associate their VR experiment with the online survey.

As seen in Table 6 below, it was noted that most of the participants completed or mostly completed the three VR activities with different levels of accuracy. The completion rate classified as "incomplete" indicates that none of the activities were completed. "50 % completed" shows that only the first two activities were completed and the last was either minimally done or not attempted. "Mostly completed" represents participants that completed all three (3) activities with a few skipped steps. The category "completed" indicates that all three activities were completed. The accuracy level of tasks was evaluated based on 3 levels: High (H), which means that the sequence of the task execution was done correctly, and the objects were placed in the right order and placement. Moderate (M) means that order and placement were mostly accurate with a few missed steps, and Low (L) means that the order and placements were not as accurate with several missed steps. Each activity data was analyzed with a relevant method, including parametric and non-parametric Analysis of variance test (ANOVA) to investigate the differences in the groups.

The normality of the time spent on the tutorial activity was investigated using the Shapiro-Wilk test. The results from the test showed the data is not normally distributed. Thus, a non-parametric approach was adopted to assess the differences between the three groups concerning the time spent on the tutorial activity. The difference in the groups was analyzed using the KW test. For the tutorial activity, it was noted that there was no significant difference ($p > 0.05$) in the distribution of the tutorial activity duration for the three groups of participants, indicating that time spent on the tutorial activity did not differ for the three groups.

TABLE VI. SUMMARY OF THE COMPLETION/ACCURACY CLASSIFICATION FOR THE THREE (3) DIFFERENT GROUPS

Completion rate/ Accuracy level							
G	Incomplete	50% complete		Mostly complete		Complete	
A	-	20 %	M	40 %	M	40 %	H
B	-	10 %	M	20 %	H	70 %	M
C	10 %	10 %	L	20 %	M	60 %	M

The normality for activity 1 duration was assessed using the Shapiro-Wilk test. From the results of the test, it was noted that the data is normally distributed. Therefore, a parametric approach was adopted to assess the differences between the three groups, for the time spent on activity 1. The difference in the groups was analyzed using ANOVA.

For this activity, there was no significant difference in the ($p > 0.05$) average time spent on activity 1 for the three groups of participants, indicating that the time spent on Activity 1 did not differ for the three groups (Figure 10).

The normality of the time spent for activity 2 was evaluated using the Shapiro-Wilk test. The results from the test showed the data is not normally distributed. Thus, a non-parametric approach was adopted to assess the differences between the three groups, concerning the time spent on activity 2. The difference in the groups was analyzed using the KW test. For activity 2, it was noted that there is no significant difference ($p > 0.05$) in the distribution of the activity 2 duration for the three groups of participants, indicating that the time spent on activity 2 did not differ for the three groups.

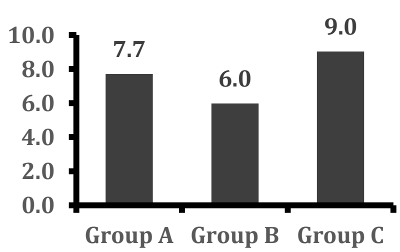


Fig. 10. The average duration of activity 1 (in minutes) for the three groups of participants

By analyzing the activity differences within each group, we noticed that all three groups spent the most time on activity 1 and the last time on the tutorial activity.

For the group differences based on the total duration of the experiment, the KW test was selected to evaluate the distribution differences. It was noted that although group C spent a longer time completing all three activities, there is no significant difference ($p > 0.05$) in the distribution of total duration for the three groups (Figure 11).

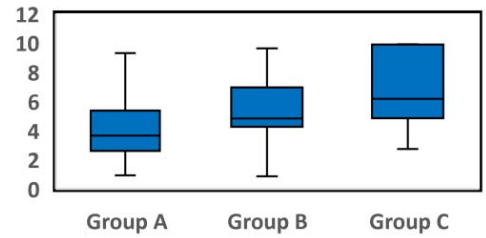


Fig. 11. The duration distribution (in minutes) for the three activities

V. DISCUSSION

The results of this study helped us to answer two research questions as follows:

RQ1: Can software controls for vertical movement provide improved accessibility for wheelchair users with task efficiency and completion rate similar to non-wheelchair users?

The result of this study shows that 80% of wheelchair users could successfully "complete" or "mostly complete" the tasks with a moderate to high level of accuracy. This is comparable to 90% for the verifying group (non-wheelchair users who used accessibility features) and 80% for the control group (non-wheelchair users) not using any such features achieving a similar level of performance and accuracy.

The open question about participants' experiences in the VR lab revealed that it "took a while to learn" how to do things, then became easy once they learned how to use the controller. Some participants found it "very realistic; size, shape, orientation, and placement of the objects around the lab". A participant commented that "as a first-time user", she was able to quickly learn hand motions and button combinations.

RQ2: Can the improved accessibility (if any) improve learning?

As shown in the result section, the question of "how easy it was to learn the task" indicates that although the verifying group and wheelchair users did not find it as easy to learn the activity (compared to the control group), both groups were able to complete the tasks with an almost similar level of accuracy and completion rate. They merely spent more time in VR to achieve similar outcomes. The average time spent in the VR for the control group was 16 minutes vs 17 minutes for verifying group and 21 minutes for wheelchair users.

Similarly, depending on the requirement to lower or raise the body to perform a task, 68% of wheelchair users found it moderately easy (rating 2-3 on the Likert scale) to perform the tasks that required lowering the body using the accessibility tool. However, only 21% of this group found it moderately easy to perform the tasks that required raising the body. Several comments obtained through the open question indicated that participants believed that a VR lab and experience like this "can positively help in all areas of science and accessibility". They found the experience very "fascinating and fun". While some users found certain parts of the object manipulation tasks challenging, several participants agreed that it was a "fun and engaging" experience that helped them understand the topic of this chemistry concept better. From the data analysis, we can notice that for the accessibility feature, software control is appreciated more in group C and that the data is not significantly different from group B (verifying group). Even though the sample size is small, we can still notice a definitive trend if more samples are taken. The vertical movement with two methods (UI button and slider) was studied and tested with three groups of wheelchair users vs. non-wheelchair users. Due to the restrictions and limitations during the pandemic, it was challenging to recruit wheelchair users and other participants in general for conducting user studies. Two (2) participants in our group C, were simulated wheelchair users. The result from one simulated wheelchair user was excluded due to cybersickness and incomplete experiments.

VI. Conclusion

Considering the difficulties faced by individuals with special needs (wheelchair users) in using VR, we focused on examining the effect of software controllers on accessibility. We have created a testing VR chemistry lab to conduct the comparison. The study was done with three groups (wheelchair users vs. non-wheelchair users), where the participants had to use two types of accessibility features to complete the tasks that required lowering or raising the body. Based on the results, the accessibility feature is shown to have helped wheelchair users to complete the activities with comparable results to non-wheelchair users in terms of completion rate, accuracy, and learning. The results also show that immersive VR environments have the potential to increase accessibility. In the future research we could potentrially explore wheelchair users' move in the horizontal direction. More research is needed to investigate various accessibility methods and also the use of AI to personalize them.

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