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Simulation and Assessment of Safety Procedure in an Immersive Virtual Reality (IVR) Laboratory

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ABSTRACT

This paper presents the early research finding of our approach to utilize an immersive virtual reality (IVR) environment as an educational tool in Science, Technology, Engineering, and Math (STEM). The proposed approach is demonstrated for the science laboratory. Realistic environment and interactions, immersive presence, automatic (in-app) data collection, and the possibility of following different educational theories such as experiential learning and use of the actual course content are among features that make this approach novel and help address existing shortcomings in STEM education, especially during COVID-19 restrictions. An initial usability study and VR presence survey were completed. Finding suggests that the majority of users found the environment realistic, memorable, and easy to use and learn. A full study is underway to compare the same application on Desktop VR (DVR) and text-based/2D safety training.

Keywords: Virtual Reality, STEM Education, Safety Training.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented and virtual realities.

1 INTRODUCTION

Recent advancement in Head-Mounted Displays (HMDs) is making them increasingly affordable and available and many organizations have been using VR to train their workforce. Military, aircraft and auto manufacturing, and medicine have been more traditional industries and domains to utilize this technology that often required extensive and expensive hardware and software setup. More recent applications using mobile HMDs include firefighter training [1], construction workers safety training [2], and experimental/pilot projects such as working with CNC machines in education [3].

In the meantime, the number of studies on the application of VR in education is increasing [4] which adds to the body of evidence that VR technology has the potential to boost learners' motivation and interest [5]. A systematic review of immersive VR by Radianti et al. [6], from 2015 to 2018, has revealed several gaps in this area. For example, authors posit that in developing such VR applications, often learning theories were not considered to guide learning outcomes. Other highlighted gaps included being a part of experimental and development work rather than applied regularly in actual teaching and concentrating mostly on usability for evaluation instead of learning outcomes.

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Laboratory courses are integral parts of many Science, Technology, Engineering, and Math (STEM) education. Physical lab experiments provide the opportunity for students to interact and gain experience using scientific equipment, expensive instruments, and dangerous materials available in chemistry labs.

Many educational institutions must follow strict safety protocols and procedures that are set by certain standards such as Hazard Communication Standard, the Laboratory Standard, Workplace Hazardous Material Information System (WHIMIS), etc. Studies show that despite such guidelines, accidents do happen in higher science education laboratories [7]. While the majority of reported accidents were "relatively" minor, some have caused permanent injuries or fatalities [8]. Lack of knowledge on the established safety procedures and insufficient training were mentioned as contributing factors to systematic safety failures.

The purpose of our study (in its first phase) is to investigate the efficacy of using three dimensional (3D) Virtual Reality (VR) technology, both Immersive (IVR) and Desktop (DVR), in STEM education. We use Chemistry lab safety procedures as a suitable example for our research context. The specific research questions are: (1) Are VR systems more effective in teaching Chemistry lab safety procedures, compared to the current teaching method (text-based /2D slides)? (2) Are performance metrics collected from the virtual environment better indicators of learning compared to instructor observation and knowledge test? (3) How IVR and DVR compare in navigation, wayfinding, object manipulation, and efficiency in completing assigned tasks?

2 THEORY AND CONCEPT

In this study, we are hypothesizing that creating a virtual chemistry lab environment (Figure 1) will be effective to help students practice the required steps and reduce human errors. This could potentially enhance students' learning, reduce the risk of accidents, and improve student's response time and performance in a chemistry lab.

Figure 1: Virtual Chemistry Lab

Existing commercial products offer simulated experiential learnings that are video-based with limited single-user 2D and 3D simulations that cannot be easily customized or are not designed based on the actual course content. Using VR technology will give instructors the ability to build dangerous scenarios such as chemical spills or a fire in the experiment station and allow students to practice their reactions and observe/record their emergency responses. Building a VR training module is a safe and cost-effective method to help academic institutions minimize the associated risks for those students who do not have sufficient training.

The flexibility of design and ability to collect data and various process metrics on student activities (with appropriate ethical guidelines) make our proposed VR-based lab a good candidate for implementing different educational methods such as experiential learning. This is in part due to observed issues with current knowledge tests that are not predicting the actual lab performance successfully. Last but not least, effective virtual labs can be a good alternative during situations such as pandemic when online courses are required. This study not only compares VR to the traditional method but also compares Immersive VR with Head-Mounted Display to Desktop VR to assess whether immersion through HMD is helpful enough to justify the cost and effort.

3 System overview

Our proposed system includes three separate areas. Since our target group (i.e., undergraduate university students) may have limited or no experience using IVR, we have included a practice room to help them gain experience using touch controllers. This was an important design consideration to avoid user frustration and potential motion sickness for some users. The immersive VR experiment runs on an Oculus Quest headset with the following specifications: Display resolution: 1440 x 1600 per eye, 72Hz refresh rate with Qualcomm Snapdragon 835 processor, and 4GB RAM, 6 degrees of freedom head and hand tracking, and two touch controllers. A desktop version of the app was built for the Windows environment and runs on any Windows 10 desktop or laptop machine. To develop the app we used a gaming PC - (Intel Core i5-/1TB HDD/ 512 Gb SSD, 16GB RAM / GeForce GTX 1650 graphic card). Unity game engine version 2019.3 and Autodesk 3Ds Max were used as the software of choice to develop the simulation and 3D models used in this simulation.

Upon running the simulation, users are expected to move around in the virtual space and complete certain tasks which include object selection and manipulation. These tasks are completed using touch controllers in IVR and keyboard/mouse combination in DVR.

The data collector gathers information about the player's behavior. All interactable objects in the scene trigger a call to the data collector. The interaction is of two types: Hover or Select. Hover happens when the players get their right or left hand near an object or that a ray is pointing towards an interactable object.
Select happens when the player hovers an object and interacts with it by pressing a button. This can be to grab an object or to click on a UI element, for example. It is noteworthy that the data collector also gives the player's a unique ID with the exact date and a random three-letter word that enables researchers to link post-experiment surveys to the exact date of the play session. The gathered data is then sent to researchers by email along with pre and post-experiment knowledge tests and surveys [9].

4 Results and Future Work

A limited user testing with six participants (2F, 4M) was conducted for IVR. Participants' age ranged between 21 to 27 with limited or no experience with IVR. The remote data collection system was still under development; therefore, only pre and post knowledge test along with SUS presence survey was administered to gain insight into the usability and to assess the sense of presence. The results revealed a high level of satisfaction on the usability scale for ease of use, memorability, learnability, pleasantness, and clarity of content provided (Figure 2).

As the study continues, we will conduct remote user testing with a completed in-app data collection system for IVR and DVR environments, and compare the VR training with traditional 2D learning material using the standard knowledge test.

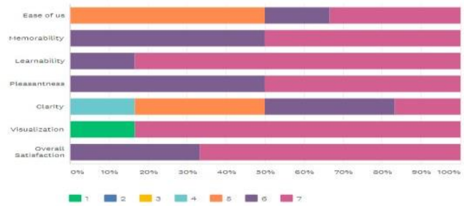

Figure 2: Usability testing result

Accessibility issues related to AR/VR physical controllers, content, and user interface design for persons with disabilities have been mentioned in several studies as another gap[10] that will exclude users with different levels of abilities (compared to abled body persons). In the next phase, we are planning to focus on developing features with accessibility considerations in mind. Some of the planned features are:

(1) Adjustable/configurable environment/ adjustable player's height that can benefit users on wheelchairs (already in development phase) (2) Design considerations for users with certain visual impairments such as color blindness. (3) Research into the design of the handheld controllers.

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