The Effect of Degree of Immersion upon Learning Performance in Virtual Reality Simulations for Medical Education

Fátima GUTIÉRREZ MS III¹, Jennifer PIERCE MS III¹, Víctor M. VERGARA, Ph.D², Robert COULTER, M.A.¹, Linda SALAND, Ph.D.¹, Thomas P. CAUDELL, Ph.D.², Timothy E. GOLDSMITH, Ph.D.³, Dale C. ALVERSON, M.D.¹
¹School of Medicine, ²School of Engineering, ³Department of Psychology, University of New Mexico, Albuquerque, New Mexico 87131 U.S.A.

Abstract. Simulations are being used in education and training to enhance understanding, improve performance, and assess competence. However, it is important to measure the performance of these simulations as learning and training tools. This study examined and compared knowledge acquisition using a knowledge structure design. The subjects were first-year medical students at The University of New Mexico School of Medicine. One group used a fully immersed virtual reality (VR) environment using a head mounted display (HMD) and another group used a partially immersed (computer screen) VR environment. The study aims were to determine whether there were significant differences between the two groups as measured by changes in knowledge structure before and after the VR simulation experience. The results showed that both groups benefitted from the VR simulation training as measured by the significant increased similarity to the expert knowledge network after the training experience. However, the immersed group showed a significantly higher gain than the partially immersed group. This study demonstrated a positive effect of VR simulation on learning as reflected by improvements in knowledge structure but an enhanced effect of full-immersion using a HMD vs. a screen-based VR system.

Keywords. Virtual Reality, Medical Simulation, Education, User Interface, Knowledge Structure.

Introduction

Virtual reality (VR) allows medical students to be immersed in lifelike situations where they can learn without suffering the consequences that may occur due to lack of experience. With VR, students are offered a type of training that would otherwise be impossible to achieve. VR training is especially important in medical education where students are expected to learn how to react in high-risk situations where human lives are potentially at stake. Developing ways to increase student competence and understanding of these issues is an ongoing pursuit in medical education as attempts to decrease medical errors and improve quality of care have been brought to the forefront of curricula in medical schools across the country [1], [2]. Simulations have been used as a method to enhance learning, training, and assessment of competence [3]-[5]. Several studies have been carried out under the auspices of Project TOUCH (Telehealth Outreach for Unified Community Health), a multi-year collaboration
between The University of Hawaii and The University of New Mexico. Previous TOUCH investigations determined whether medical students could work as a team within a virtual problem-based learning environment. The study concluded that team performance within the VR environment was as good as in real life team sessions [6]. Another study investigated whether medical student learning could be objectively demonstrated within VR training. The study found evidence of significant learning as a function of a single VR training experience [7]. Despite a long-standing interest in VR training, few studies have measured learning effects in different VR environments. Using first-year medical students as the study subjects at the University of New Mexico School of Medicine the students were randomly divided into two groups; one group used a fully immersed VR environment using a head mounted display (HMD) and another group used a partially immersed (computer screen) VR environment. The study aims were to determine whether there were significant differences within and between the two groups as measured by changes in knowledge structure before and after the VR simulation experience.

1. Materials and Tools

1.1. The Study Population

Twenty five volunteers were obtained from the first year medical school class at the University of New Mexico during their neuroscience block and randomly divided into two groups: Fully-immersed, where participants wore a stereoscopic head-mounted display, or partially-immersed, where participants interacted with the VR simulation via a computer monitor. Both groups used a joystick for navigation, locomotion and manipulation of objects within the VR simulation. Each group used the same problem-based case. Informed consent was obtained from each participating student.

1.2. The Flatland Platform

Flatland served as the software infrastructure [8]. It is an open source visualization/VR application development environment, created at The University of New Mexico. Flatland allows software authors to construct, and users to interact with, arbitrarily complex graphical and aural representations of data and systems. It is written in C/C++ and uses the standard OpenGL graphics language to produce all graphics. Flatland is designed to integrate any position-tracking technology. A tracker is a multiple degree of freedom measurement device that can, in real time, monitor the position and orientation of multiple receiver devices in space, relative to a transmitter device. In the standard immersive Flatland configuration, trackers are used to locate hand held wands and to track the position of the user's head. Head position and orientation are needed in cases that involve the use of head mounted displays or stereo shutter glasses. The events within the virtual environment are controlled by an Artificial Intelligence (AI) engine. This AI engine was a forward chaining IF-THEN rule based system that specifies the behavior of objects in the VR world. The rules governing the physiology of the avatar were obtained from subject matter experts. The rules were coded in a C computer language format as logical antecedents and consequences. The AI loops over the rule base, applying each rule's antecedents to the current state of the system, including time, and testing for logical matches. Matching
rules are "fired," modifying the next state of the system. Time is a special state of the system that is not directly modified by the AI, but whose rate is controlled by an adjustable clock. Since the rate of inference within the AI is controlled by this clock, the user (or student) is able to speed up, slow down, or stop the action controlled by the AI. This feature allows a user to learn from his/her mistakes by repeating a scenario.

1.3. The Virtual Environments

In the fully immersed virtual reality environment, students wore a head-mounted display with trackers and used a joystick for hand movement, which allowed the students a sense of presence within the virtual environment. The interactions between user and virtual environment were controlled by a joystick equipped with a six degree of freedom tracking system, buttons, and a trigger. The user could pick up and place objects by moving the virtual hand and pulling the wand's trigger. Participants were able to examine the virtual patient by independently controlling their viewpoints and motion within the virtual world. In this fully-immersed environment, the student could see only the virtual world.

In the partially immersed VR environment, a student did not wear a head-mounted display, but saw the patient on a computer screen and used a mouse to rotate the viewpoint. The navigation and manipulation of objects within the virtual environment occurred by using a joystick, similar to the fully-immersed environment. Students were still able to examine and interact with the virtual patient, although, they were also aware of the outside environment (see Figure 1).

![Figure 1. Student using Full Immersion vs. Partial Immersion](image)

2. Procedures and Methods

2.1. Experimental Procedures

Participants were tested individually. After reading and signing a statement of informed consent, students were oriented to the VR equipment. After the orientation, the students were directed to a website where they filled out a demographic questionnaire and then watched an instructional video on the use of the VR equipment. The website also contained links to interactive, labeled diagrams of the VR equipment and links to head-injury reference materials such as brain section diagrams, schematics, short video animations and textual information. When the students were finished watching the video, they were allowed to view additional reference materials and to practice using...
the VR equipment until they felt comfortable in locomotion, navigation and manipulation objects. The students were then directed back to the web site for step-by-step instructions for the experiment. Before starting the experiment, students were given a knowledge assessment test that consisted of rating the relatedness of 72 pairs of concepts critical to the case, 36 of which were previously defined to be related by a expert and 36 unrelated. The terms were selected by having subject matter experts identify the most important concepts related to a traumatic head injury involving an epidural hematoma. The students participating in the VR were immersed in a scenario where they were the first responders in an automobile accident that involved head trauma. Next, they read a web-based, textual orientation to the clinical scenario and, based on this, they were asked to complete a list of known and anticipated problems. Then they were given 30 minutes to enter the virtual environment (see Figure 2) and to perform a physical exam on the virtual patient.

![Figure 2](image.png)

**Figure 2.** A depiction of what the students saw in the virtual environment

After performing the physical exam, participants read a summary of the expected physical exam findings and were then able to treat the patient as they chose. Next, they read a case conclusion, explaining the virtual patient's injuries, follow-up or confirmatory studies, and the expected actions to be taken once the patient arrived at an ER. Finally, the participants completed the knowledge assessment exercise a second time.

### 2.2. Learning Evaluation Method

VR learning was evaluated by having the students perform the relatedness ratings task both before and immediately following VR training [9], [10]. The Pathfinder scaling algorithm was then applied to each student's pre and post-learning ratings to derive two knowledge structures. Previously, a group of subject matter experts had rated the relatedness of the hematoma concepts, and Pathfinder was used to derive a single
expert knowledge structure. This expert knowledge structure was then used as a gold standard against which to compare the students' knowledge structures. A similarity score, ranging from 0 to 1, was used to compare how close the student's knowledge structures were to the expert's. VR learning would be reflected by higher similarity scores after the VR experience than before. In addition, the difference between VR learning of the fully-immersed and partially-immersed groups was evaluated by examining changes in students' knowledge structures.

2.3. Statistical Analysis

Knowledge acquisition and impact on learning of the VR simulation was examined by measuring changes in knowledge structure. Knowledge structures of the students were compared to the expert knowledge structure using Pathfinder to determine similarity coefficients before and after VR experience and then between the two training groups. If learning is occurring, the student's knowledge structure should correlate more strongly with the expert's knowledge structure after the experience. Power analysis determined that sample size of 20 (10 in each group) will achieve 80% power to detect a difference of 0.08 between pre-test and post-test scores with an estimated SD of 0.12 and a significance level of 0.05 using a paired t-test. The similarity scores of the two student cohorts, fully-immersed and partially immersed, before and after the VR experiments were compared using analysis of variance where full-immersion vs. partial immersion was the independent variable.

3. Results

There were a total of 25 students who completed training, 13 students who were fully immersed and 12 students who were partially immersed. Pathfinder was computed on each student's raw ratings to derive a knowledge network. These networks were then compared to the expert knowledge network using a method that produces a similarity index (s) that varies from 0 to 1. The mean similarity scores are shown in Table 1.

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<th>Table 1. Mean similarity scores (and standard deviations)</th>
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A 2x2 repeated measures analysis of variance was performed with pre vs. post simulation experience as a within-subjects variable and fully vs. partially immersed as a between-subjects variable. There was a significant interaction between groups and time, F(1,23)=4.548, p=0.044, indicating that the difference between pre and post similarity scores for the fully immersed group was different from the pre/post difference for the partially immersed group. The overall pre/post difference was also significant, F(1,23)=30.734, p<0.001, but the overall group difference (fully vs. partially immersed) was not significant F(1,23)=0.05. Matched pairs t-tests were then
performed comparing pre and post simulation scores for the two groups separately. The difference for the fully immersed group was highly significant t(12)=5.115, p<0.001 and the difference for the partially immersed group was also significant t(11)=2.625, p=0.024.

4. Conclusion

The results showed that both groups benefited from the VR simulation training as measured by the significant increased similarity to the expert knowledge network after the training experience. However, the immersed group showed a significantly higher gain than the partially immersed group. This study demonstrated a positive effect of VR simulation on learning as reflected by improvements in knowledge structure but an enhanced effect of full-immersion using a HMD vs. a screen-based VR system. Future studies should be developed to understand better the reasons for those differences.

References


