Information Recall In A Virtual Reality Disability Simulation

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ABSTRACT

The purpose of this paper is to investigate the effect of the sense of presence on one aspect of learning, information recall, in an immersive virtual reality (VR) disability simulation. Previous research has shown that the use of VR technology in education may facilitate improved learning outcomes, however, it is still an active research topic as the learning outcomes can vary widely. We hypothesized that a higher level of immersion and involvement in a VR disability simulation that leads to a high sense of presence will help the user improve information recall. To investigate this hypothesis, we conducted a between subjects experiment in which participants were presented information about multiple sclerosis in different immersive conditions and afterwards they attempted to recall the information. We also looked into whether there is any adverse effect of cybersickness on the information recall task in our disability simulation. The results from our study suggest that participants who were in immersive conditions were able to recall the information more effectively than the participants who experienced a non-immersive condition.

CCS CONCEPTS

• **Human-centered computing → User studies**; *Walkthrough evaluations*; *Empirical studies in HCI*;

KEYWORDS

Games for health, learning, persuasion, or change (primary keyword), Virtual/Augmented Reality, User Studies, Information Recall

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Figure 1: Participants playing the game in four conditions i.e., Desktop-WC, Oculus-WC, Desktop-GP, and Oculus-GP (ordered from top to bottom) and their respective view in the VR.

1 INTRODUCTION

The advantages of using VR to facilitate teaching educational objectives are similar in many ways to the advantages of using a computer or interactive simulation, particularly a three dimensional (3D) computer simulation. Chou [Chou 1998] asserts that "researchers attribute success of simulations to the empowerment of students, the unique instructional capabilities, the support for new instructional approaches, the development of cognitive skills, and the development of attitudes". While many studies found that the usage of VR in education is helpful [Pantelidis 2010; Piovesan et al. 2012; Psotka 2013], it is not known if immersive VR technology is necessary or beneficial over 3D computer simulation for such learning-based applications. Evaluating learning in VR is a difficult problem to approach directly, especially because measurement of conceptual learning is not well defined. Rather than attempting the evaluation of conceptual learning as a whole, in this paper, we investigate the impact of immersive VR displays and interfaces in an information recall task as a more achievable and quantifiable example of the learning activity. We use a disability simulation (DS) in a game-like virtual environment (VE). In our study, we use the Oxford dictionary definition [OD 2017] of "recall" as "bring (a fact, event, or situation) back into one's mind" or simply "to remember". In that sense, information recall is how well people can remember the information they learned previously.

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Specifically, this study focuses on how presence, involvement, and flow in immersive VR disability simulation affect information recall. Presence, involvement, and flow are three common user experience factors that can be affected by immersion. Presence is defined as "the subjective experience of being in one place or environment" [Witmer and Singer 1998] and is related to the concept of immersion and sometimes referred to as mental immersion [Roussos et al. 1999]. Randolph et al. [Randolph et al. 1998] calls immersion "the sensation of being surrounded by a completely other reality, as different as water is from air, that takes over all of our attention, our whole perceptual apparatus". Although, immersion is a description of a technology and can be an objective description of what a particular VR system provides, presence, on the other hand, is a subjective state, the psychological sense of being "there" in a VR. Similarly, involvement is a psychological state experienced as a consequence of focusing one's energy and attention on a coherent set of stimuli or meaningfully related activities and events. Involvement depends on the degree of significance or meaning that the individual attaches to the stimuli, activities, or events. According to Witmer et al. [Witmer and Singer 1998], both involvement and immersion are necessary to experience presence. While, involvement is defined as "a motivational continuum toward a particular object or situation" [Rothschild 1984], flow, on the other hand, explains the cognitive evaluation and emotional outcomes of the experience. The Presence-Involvement-Flow Framework (PIFF^2) [Takatalo et al. 2011] is a psychological research framework to study presence, involvement and flow in video games.

However, it is unclear how presence, involvement, and flow affect learning. Some researchers have found that feeling high sense of presence greatly improves learning outcomes [Schank and Saunders 2001], and participants perform better in procedural memorization task when using a highly immersive VR system [Sowndararajan et al. 2008]. Conversely, other researchers have found that increased presence does not always result in better learning [Mikropoulos and Natsis 2011; Persky et al. 2009]. Hence, it is still an active research topic.

Moreover, learning has been minimally studied with respect to VR-based DS. According to Flower et al. [Flower et al. 2007] a DS is "an approach to modifying attitudes regarding people with disabilities is to place people without disabilities in situations that are designed for them to experience what it is like to have a disability". Several approaches have been used to encourage or promote the development of more positive attitudes toward people with disabilities. Educating people without disabilities about people with disabilities using accurate information is one of them. Moreover, the use of various disability simulations among college students has been reported at several campuses [Flower et al. 2007]. In some research, the concept of DS strategies have sometimes been criticized for a reported lack of evidence of their effectiveness [French 1992].

One potential threat to DS effectiveness in VR is cybersickness, which could potentially have negative effects on learning [POLCAR and HOREJSI 2013]. Head Mounted displays (HMD) are highly immersive. However, because of this higher immersion users can also experience negative side effect, such as cybersickness or simulator sickness. Cybersickness is similar to motion sickness in that it generally results in feelings of nausea, dizziness, vertigo, sweating etc. Even though, cybersickness has been studied since 70s, the recent availability and popularity surge of VR has made the topic even more relevant to study. Cybersickness is thought to be the result of the discrepancy between the visual input and the vestibular system input. That is, the motion being seen by the eye in virtual world is different than the motion being experienced by the physical body. There are many different ways to assess simulator sickness, however, the most popular is the Simulator Sickness Questionnaire (SSQ) published by Kennedy et al. [Kennedy et al. 1993].

The disability we choose to simulate in our experiment is Walking (Gait) Difficulties caused by a disease called Multiple Sclerosis (MS). MS involves an immune-mediated process in which an abnormal response of the body's immune system is directed against the central nervous system (CNS), which is made up of the brain, spinal cord and optic nerves. The exact antigen–or target that the immune cells are sensitized to attack–remains unknown, which is why MS is considered by many experts to be "immune-mediated" rather than "autoimmune".

In this paper, we investigate the effect of presence on information recall, using a video game like DS. From the literature review, and also from the result of our pilot study, we hypothesize that there is a significant effect of the user's sense of presence on the user's information recall. The results in this paper show improved information recall when users feel a higher degree of presence in virtual environment (VE). While investigating the effect of presence, we also explore the symptoms of cybersickness while users are in different conditions (sec. 4.1). Then we looked into how cybersickness plays a role on information recall task in our virtual environment.

The rest of our paper is organized as follows. In section 2, we briefly review related research on immersion, presence, learning, cybersickness and disability simulation. In section 3, we present our hypotheses. Section 4, 5 and 6 describe our Methods, Study Procedure and Metrics respectively. Section 7 introduces our data analysis results and we give a detailed discussion on our findings in section 8. We conclude and give a direction to possible future work in section 9.

2 BACKGROUND AND RELATED WORK

2.1 Immersion, Involvement, and Presence

Physical immersion can be defined as a function of the simulator's technology [Dalgarno and Lee 2010; Ragan et al. 2010; Stevens and Kincaid 2014]. In virtual environments, immersive systems generally use head-tracking technology along with the minimization of real world stimuli [Bailenson et al. 2008]. The degree of physical immersion is an active literature topic and it is generally thought that increasing the immersion of a virtual environment will produce a stronger sense of presence.

The literature is replete with studies that not only attempt to categorize factors of presence but also highlight simulator attributes that influence an individual's sense of presence [Winn 1993; Witmer and Singer 1998]. According to Moreno et al. [Moreno and Mayer 2002], HMDs are more immersive and users may experience higher presence in HMDs, which is commonly measured through questionnaires, such as the Witmer and Singer Presence Questionnaire (PQ) [Witmer and Singer 1998]. Similarly, the PIFF^2 is commonly used to evaluate presence in video games. PIFF[2] is also considered a validated metric to measure involvement (a motivational continuum toward a particular object or situation), and flow (subjective cognitive-emotional evaluation) in the game [Takatalo et al. 2011].

2.2 Disability Simulation in VR

A number of approaches have been implemented to foster more positive attitudes toward people with disabilities. Flower et al. [Flower et al. 2007] summarizes some of the categories as- showing films presenting a positive image of people with disabilities, educating people without disabilities about people with disabilities using accurate information, and interaction between individuals with and without disabilities in an equal-status relationship. However, the categories of DS strategies have sometimes been criticized for a reported lack of evidence of their effectiveness [French 1992]. Despite the lack of data regarding its effectiveness and the concerns about negative experiences, disability simulation remains a common approach to attempt positive modification of attitudes regarding people with disabilities [Hartwell 2001]. VR is also used in disability awareness. Pivik et al. [Pivik et al. 2002] illustrate that VR is effective in teaching children with and without disabilities about accessibility and attitudinal barriers.

2.3 Education in Virtual Environments

Recent advancement of technology is offering many innovative and promising learning environments [Roussos et al. 1999; Stansfield et al. 2000; Winn 1993]. VR is now being used as a means to learn not only concepts and procedures but also basic and complex skills in many fields i.e., conventional flight simulators [Zacharia 2003], surgical simulators [Satava and Jones 1997], and also in education [Pantelidis 2010; Piovesan et al. 2012; Psotka 2013]. VEs can be used to make the learning more interesting and fun with the purpose of improving the motivation and attention. Additionally, the usage of VEs in education is also cost effective.

Educational VR systems have been developed for the purpose of helping students to learn conceptual information and principles. For example, researchers have prototyped immersive VR systems for mathematics education [Kaufmann et al. 2000; Roussou et al. 2006] and for learning complex principles of physics [DEDE and SALZMAN 2001].

Maria el al. [Roussos et al. 1999] describes the design, evaluation, and lessons learned from a project involving the implementation of an immersive virtual environment for children called NICE (Narrative-based, Immersive, Constructionist/Collaborative Environments). The goal of the NICE project was to construct a testbed for the exploration of virtual reality as a learning medium.

2.4 The Relationship between Presence and Learning

The relationship between presence and learning is unclear because many studies have found conflicting results. According to Schank et al. [Schank and Saunders 2001], feeling present, feeling that the consequences of actions played in virtual environments and simulations are real can dramatically improve learning outcome. In a study related to the memorization of object information, Mania et al. [Mania et al. 2005] found evidence that higher rendering quality significantly increase object recognition. Several researchers have investigated the effects of various components of immersive VR [Arthur et al. 1997; Mania and Chalmers 2001], as well as interaction techniques [Brooks 1999] on memorization of spatial layouts of objects. Sowndararajan et al. [Sowndararajan et al. 2008] found that even when greater emphasis on learning new information that is not bound to the specifics of the VE, users performed significantly better in a procedural memorization task when they used a more immersive VE.

2.5 Cybersickness

While immersive VR technology allows the users to feel a higher degree of presence in the virtual environment, the user can also experience some negative side effects such as disorientation, nausea, headaches and difficulties with vision [Stanney et al. 2003]. When caused by virtual simulators these effects are known as cybersickness or simulator sickness (SS). Besides the human factors (i.e., age, gender, previous experience) [Stanney et al. 2003], simulator factors have an impact on cybersickness as well, such as exposure duration, field of view (FOV), interpupillary distance (IPD), position-tracking error, refresh rate, lag, and scene complexity. Factors such as longer exposure, bigger FOV, and incorrect IPD amongst others can induce increased cybersickness. Previous research on navigational controls [Stanney et al. 2003] showed that the degrees of freedom (DOF) of the navigational control can have a positive relation with cybersickness: the more DOF, the larger cybersickness.

3 HYPOTHESES

The main goal of this research is to investigate the effect of presence on information recall, an aspect of learning, in a VR disability simulation. We also look into the effects of cybersickness on recall. To reach our goal, we analyzed each participant's learning evaluation score from a Multiple Sclerosis Questionnaire (MSQ)–a questionnaire based on information presented in our VE–in different conditions (sec. 4.1) and find out whether any significant effect exists or not. Based on the previous literature, the following hypotheses are to investigate the effects of presence on learning:

H1: Using a tracked HMD in a VE will improve user's sense of presence in a VR-based disability simulation a compared to a desktop monitor.

H2: Using a physical wheelchair interface in a VE will improve user's sense of presence in a VR-based disability simulation as compared to a game pad interface.

H3: An HMD will significantly increase the user's experience of cybersickness in a VR-based disability simulation.

H4: HMD users will demonstrate significantly improved information recall as compared to desktop display users.

H5: With a physical wheelchair interface users will demonstrate significantly improved information recall as compared to gamepad users.

Table 1: Descriptive statistics for participants' information for our four study conditions (sec. 4.1).

Conditions	Male	Female	VR Experience	Mean Age (SD)
Oculus-WC	13	4	1	19.4 (4.9)
Oculus-GP	12	6	1	21.3 (4.1)
Desktop-WC	13	5	2	20.7 (5.0)
Desktop-GP	15	2	2	19.9 (4.5)

4 METHODS

4.1 Study Conditions

We choose to recruit young university students for our user study. They are mostly familiar using computers in their daily life for studying, doing homework, playing games etc. In our study, one of the interfaces is a gamepad, a gaming accessory that is known to most of the participants. As the VR accessories are becoming affordable for the consumer, we chose one of the popular HMD called Oculus Rift.

To examine how presence affects information recall in disability simulation, there were four conditions in our study. These four conditions are: Wheelchair interface with Oculus (Oculus-WC), Wheelchair interface with Desktop (Desktop-WC), Game-pad interface with Oculus (Oculus-GP), Game-pad interface with Desktop (Desktop-GP). Participants were assigned to one of the four conditions randomly. In all four conditions, participants were asked to navigate around the virtual model of AT&T center and listen to the information about MS presented as audio at specific markers located around the virtual AT&T center.

4.2 Participants and Selection Criteria

A pilot study with 10 participants was conducted to provide a formative evaluation of the procedures and instruments [Chowdhury et al. 2017a,b]. Then we recruited 70 unpaid undergraduate students from University of Texas at San Antonio (17 of them were female) for the actual experiment. Participants were recruited without any known mental or physical impairments. All participants had normal or corrected-to-normal vision. The mean age of the participants were 20.3 years (SD 4.6). Only six of them had prior VR experiences of using Google Cardboard once or twice, but none have used Oculus DK2. Three participants used a wheelchair before due to injury, sickness, or disability. Table 1 lists the descriptive statistics of the participants for our four study conditions.

4.3 System Description

The VE was designed in Unity 5, a multi-platform game development engine from Unity Technologies. We used Oculus Rift DK2 HMD for our immersive condition. The Oculus Rift DK2 has a resolution of 960 x 1080 pixel per eye with a refresh rate of 60 Hz and a 100 degree field of view.

For Oculus-WC and Oculus-GP conditions, due to the requirements of the Oculus DK2, a high performance computer was used in this study to render the VE. The system was equipped with Intel (R) core (TM) i7 processor (3.30 GHz), 16GB DDR3 RAM, NVIDIA GeForce GTX 980 display card with 4GB of dedicated video memory, and a 64-bits Windows 8.1 Pro operating system.

We had two navigational interfaces for the participants to control movement of their avatar in the VE. These two interfaces are "Wheelchair" and "Gamepad". In Oculus-WC and Desktop-WC conditions, participants interacted with a real wheelchair to navigate through the virtual world. The wheelchair was mounted on top of two bike trainers (Figure 1) with two android phones attached to its two wheels. The rotation data captured from those two phones' gyros were used to control the movement in the VE. In Oculus-GP and Desktop-GP conditions, the participants used a Microsoft Xbox 360 wireless controller to control their movement in the VE. Figure 2 shows our system schematics which illustrates how the different components in our study interact with each other.

We used a UE 4000 Headphones for the audio.

4.4 Virtual Environment

Each year people with MS (along with their friends and family) gather together at AT&T center and participate in an annual fundraising walk. In our disability simulation, we developed a virtual model of the AT&T center. Similar to the real walk, participants in our study had to navigate around the virtual AT&T center and listen to the audio information presented along their path. The actual perimeter of AT&T center that was modeled in the VE was around 1.75 KM (Figure 4 shows the bird's eye view of the virtual AT&T center). Generally, it takes 20–25 minutes to complete the whole path at normal walking speed. In the VE, navigation capability was revoked while the information was playing to ensure minimal distraction (and also so that no participant misses any information). That makes the VE experience lasts for about 30–35 minutes. The camera was first person view mode. If the participant looked down, they could see their virtual avatar sitting on a wheelchair (Figure 3) except in the Desktop-WC condition where they can literally see themselves on the actual wheelchair.

In our VE, we choose to present the information in audio format because from our pilot study we found out that hearing the information in audio is less distracting than reading the same information as text, likely due to he resolution limitations of the DK2 HMD. To motivate the participants we gave them trophies as they progressed along the virtual AT&T center's path.

5 STUDY PROCEDURE

5.1 Consent

At the beginning of the study, each person had to sign an ethics board approved consent form to participate in the study. In the consent form, we also asked them whether we can use the data in our research. After that, a brief introduction was given about the system and what they are expected to do in the study.

5.2 Study Experience

After the brief introduction, the participants were asked to sit on the designated wheelchair if they were assigned to one of two wheelchair conditions i.e., Oculus-WC or Desktop-WC. However, for Oculus-GP or Desktop-GP conditions, the participants were seated on a traditional revolving chair. In all four conditions, they

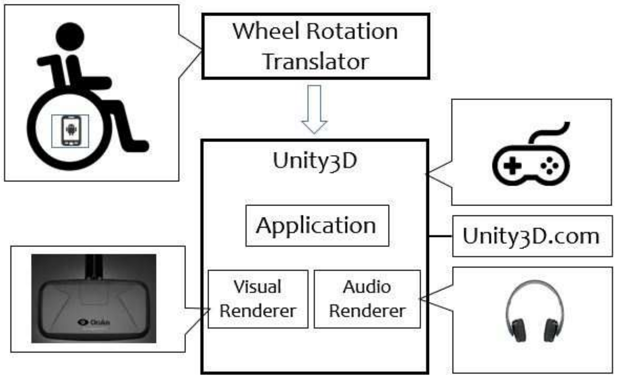


Figure 2: The system schematics for two Oculus conditions (i.e., Oculus-WC and Oculus-GP). Wheelchair is used in Oculus-WC and Game-pad is used in Oculus-GP condition.

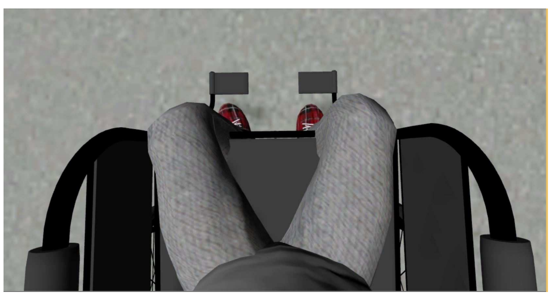


Figure 3: Participant looking at their self avatar sitting on wheelchair.

Figure 4: Birds eye view of virtual AT&T center's top view (path of participants shown in arrows).

wore the headphone. When participant was comfortable enough to start the study, we started the VR experience. The participants navigated through the AT&T center and had to stop each information board placed along their path. They listened to the audio information while waiting in front of the board. The movement capability was restricted while the audio was playing. When audio was finished, they could start moving again. The whole VR experience continued for about 30–35 minutes.

5.3 Post-Study Questionnaire

After finishing the VR experience, the participants filled out a Multiple Sclerosis Questionnaire (MSQ), which consists of questions about the Multiple Sclerosis information presented in the VE. They also filled out a Simulator Sickness Questionnaire (SSQ) and a Presence Questionnaire (PIFF^2). In general, the whole study took approximately 45–50 minutes per participant (VE experience + questionnaire). Participants did not receive any financial benefit.

6 METRICS

6.1 MSQ Score

In the VE, the path of the participants contains virtual information boards. These boards play audio information about MS when the participants approach towards them in VE. After the VE experience was completed, we asked the participants 11 questions (MSQ) based on the audio information presented in the game. Every question carried equal weight of 30 towards the final MSQ score. The MSQ score denotes how well a participant was able to recall the information about MS which they learned in the VE. The full questionnaire can be found here [MSQ 2017].

6.2 Simulator Sickness Questionnaire (SSQ)

The Simulator Sickness Questionnaire (SSQ) is a standard 16 items questionnaire where each item asks about participants' different physiological discomfort [Kennedy et al. 1993]. Each item can be rated from "None" to "Severe" where "None" quantifies as 0 and "Severe" quantifies as 3 towards the calculation of SSQ score. SSQ has three sub-scales of scores-***nausea***, ***oculomotor***, and ***disorientation***. The ***SSQ total*** score is calculated from these three sub-scales.

6.3 Presence Questionnaire (PIFF^2)

The PIFF^2 is a 14 item questionnaire where each item asks about participants' sense of presence, involvement, or flow. Each item can be rated from "None" to "Severe" where "None" quantifies as 0 and "Severe" quantifies as 3 towards the calculation of scores in PIFF^2. The four dimensions of scores–***presence***, ***involvement***, ***cognitive evaluation***, and ***emotional outcome***–of PIFF^2 contribute towards the final scores of three sub-scales–***presence***, ***involvement***, and ***flow*** [Takatalo et al. 2011].

6.4 Statistical Analysis

A Shapiro-Wilk test indicated that data was normally distributed. Thus, using parametric tests, we conducted the analysis from two perspectives– (1) grouping conditions into two variables (i.e., Display and Interface) to investigate the interactions between the variables and (2) comparing the four conditions, correcting for multiple comparison. Thus, we first performed two-way ANOVAs and then used two-tailed independent sample t-tests with Bonferroni correction for post hoc analysis to investigate effects and interactions of the two variables at two levels each - Display i.e., immersive (Oculus) vs non-immersive (Desktop) and Interfaces i.e., wheelchair vs game-pad. Pearson Correlation was used to see how variables are correlated i.e., presence vs information recall, involvement vs information recall etc. We compared the MSQ, SSQ and PIFF^2 data of participants for all four conditions i.e., Oculus-WC, Desktop-WC, Oculus-GP and Desktop-GP. All the statistical analyses were performed using IBM SPSS version 19.

7 RESULTS

In our user study we had four between subject conditions–Oculus-WC, Desktop-WC, Oculus-GP and Desktop-GP. To investigate interactions between display and interface, we further categorized them into two independent variables- (a) Display type–immersive (Oculus-X) and non-immersive (Desktop-X) [X = either WC or GP] and (b) Interface–wheelchair (X-WC) and game-pad (X-GP) [X = either Oculus or Desktop].

7.1 Correlation Result for Four Conditions

In our analysis using Pearson Correlation, we found a significant positive correlation between ***presence*** (M = 11.68, SD = 1.62) and ***information recall*** (M = 220.86, SD = 44.90), r = 0.77, $p \leq 0.001$, n = 70. There was also a positive correlation between ***involvement*** (M = 6.66, SD = 1.49) and ***information recall*** (M = 220.86, SD = 44.90), r = 0.72, $p \leq 0.001$, n = 70. However, ***cognitive evaluation*** and ***emotional outcome*** were not statistically correlated with ***information recall*** in our analysis. Table 2 lists correlation results for different dimensions of PIFF^2 questionnaire with ***information recall***.

Table 2: Correlation between information recall and different dimensions of PIFF^2 scale. (ns = statistically not significant).

Subscale	Correlation (p-value)			
	Oculus-WC	Desktop-WC	Oculus-GP	Desktop-GP
Presence	0.87 (0.001)	0.70 (0.012)	0.73 (0.016)	0.79 (0.012)
Involvement	0.73 (0.017)	0.68 (0.015)	0.66 (0.04)	0.63 (0.012)
Cognitive Eval^n	0.28 (ns)	0.29 (ns)	0.24 (ns)	0.33 (ns)
Emotional Outcome	-0.41 (ns)	0.01 (ns)	0.03 (ns)	0.06 (ns)

7.2 Presence and Involvement Result (PIFF^2 Score)

We ran two-way ANOVAs on each dimension of PIFF^2 (***presence***, ***involvement***, ***cognitive evaluation***, and ***emotional outcome***) and independent-samples t-tests with Bonferroni correction to investigate effects and interactions influenced by display and interface. For dimension ***presence***, with two-way ANOVA, we found significant main effects of Display (F(1,66) = 4.547, p = .037, q partial η^2 = .064), Interface (F(1,66) = 16.396, p < .001, q partial η^2 = .199) and a significant interaction between Display and Interface F(1,66) = 13.431, p < .001, q partial η^2= .169). For dimension ***involvement***, with two-way ANOVA, we found significant main effects of Display (F(1,66) = 10.223, p = .002, q partial η^2 = .134), Interface (F(1,66) = 11.263, p = .001, q partial η^2 = .146) and a significant interaction between Display and Interface F(1,66) = 4.711, p = 0.034, q partial η^2 = .067). The dimension ***cognitive evaluation*** did not show any statistically significant differences with two-way ANOVA. For the ***emotional outcome*** dimension, with two-way ANOVA, we found significant main effects of Display (F(1,66) = 16.546, p < .001, q partial η^2 = .2), Interface (F(1,66) = 36.304, p < .001, q partial η^2 = .355) and a significant interaction between Display and Interface F(1,66) = 6.43, p = 0.014, q partial η^2 = .089).

7.2.1 Display: Immersive vs Non-immersive. For dimension ***presence***, there was a statistically significant difference between group means as determined by t-test (immersive (M = 12.17, SD = 2.503) and non-immersive (M = 9.11, SD = 3.132) conditions; t(68) = 4.511, $p \leq 0.001$).

For dimension ***involvement***, there was a statistically significant difference between group means as determined by t-test (immersive (M = 6.11, SD = 1.491) and non-immersive (M = 4.77, SD = 1.536) conditions; t(68) = 3.712, $p \leq 0.001$).

For dimension ***emotional outcome***, there was a statistically significant difference between group means as determined by t-test (immersive (M = 15.11, SD = 2.908) and non-immersive (M = 12.71, SD = 3.054) conditions; t(68) = 3.367, $p \leq 0.001$).

These results suggest that the participants in immersive conditions felt a high sense of presence and involvement in VE than the participants in non-immersive conditions.

7.2.2 Comparing the Four Conditions. We ran one-way ANOVAs on four dimensions of PIFF^2 (***presence***, ***involvement***, ***cognitive evaluation***, and ***emotional outcome***) for the four study conditions.

For dimension ***presence***, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 13.147, $p \leq 0.001$). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-WC (M = 11.83, SD = 3.015), Desktop-WC (M = 10.67, SD = 2.449), and Oculus-GP (M = 12.67, SD = 1.879), were significantly different (p < .05) than the Desktop-GP (M = 7.47, SD = 2.982).

The dimension ***cognitive evaluation*** did not show any statistically significant difference (F (3, 66) = 1.205, p = 0.315) among any of the group of two conditions taken from our four study conditions i.e., Oculus-WC vs Oculus-GP, Oculus-GP vs Desktop-WC etc.

For dimension ***involvement***, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 6.930, $p \leq 0.001$). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-WC (M = 6.11, SD = 1.641), and Oculus-GP (M = 6.17, SD = 1.339), were significantly different (p<.05) than the Desktop-GP (M = 4.18, SD = 1.425).

For the ***emotional outcome*** dimension, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 4.724, p = 0.005). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-WC (M = 15.17, SD = 3.148), and Oculus-GP (M = 15.22, SD = 2.734), were significantly different (p < .05) than the Desktop-GP (M = 12.00, SD = 3.571).

7.2.3 Interface: Wheelchair vs Game-Pad. For dimension ***presence***, there was a statistically significant difference ($p < .001$) between group means as determined by t-test wheelchair ($M = 11.9$, $SD = 1.451$) and game-pad ($M = 9.319$, $SD = 2.401$) conditions.

For dimension ***involvement***, there was a statistically significant difference ($p = .001$) between group means as determined by t-test (wheelchair ($M = 6.29$, $SD = .208$) and game-pad ($M = 5.12$ $SD = .249$) conditions.

For dimension ***emotional outcome***, there was a statistically significant difference ($p < .001$) between group means as determined by t-test (wheelchair ($M = 15.50$, $SD = 3.462$) and game-pad ($M = 11.57$, $SD = 2.662$) conditions.

Table 3: Descriptive statistics for PIFF^2.

Dimensions (p-value)	Oculus-WC Mean (SD)	Desktop-WC Mean (SD)	Oculus-GP Mean (SD)	Desktop-GP Mean (SD)
Presence (≤ 0.001)	11.83 (3.015)	10.67 (2.449)	12.67 (1.879)	7.47 (2.982)
Involvement (≤ 0.001)	6.11 (1.641)	5.33 (1.455)	6.17 (1.339)	4.18 (1.425)
Cognitive Eval^n (0.315)	9.33 (1.910)	9.83 (2.203)	9.61 (1.819)	8.71 (1.359)
Emotional Outcome (0.005)	15.17 (3.148)	13.39 (2.380)	15.22 (2.734)	12.00 (3.571)

Table 3 and Figure 5 shows the Mean (SD) and significance level of PIFF^2 dimensions score for participants in different conditions.

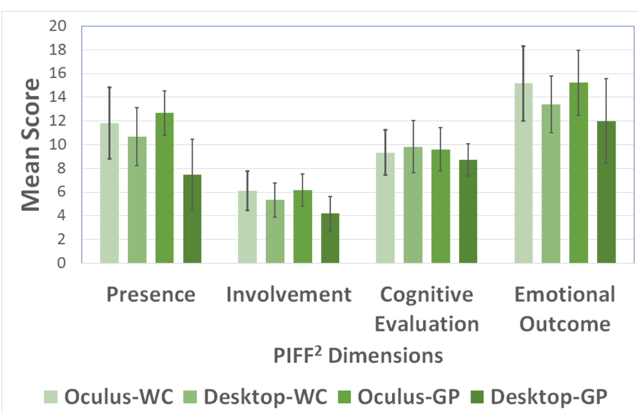
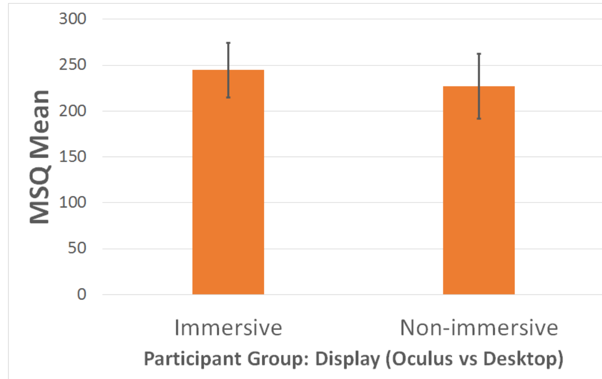


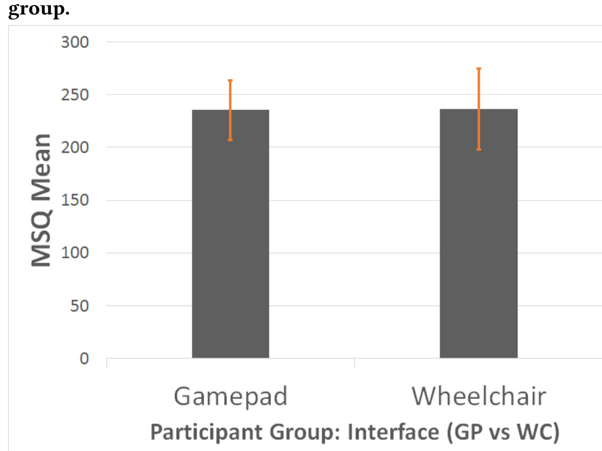
Figure 5: PIFF^2 dimensions score comparison among participant groups. The whiskers represent standard deviation.

7.3 Information Recall Result (MSQ Score)

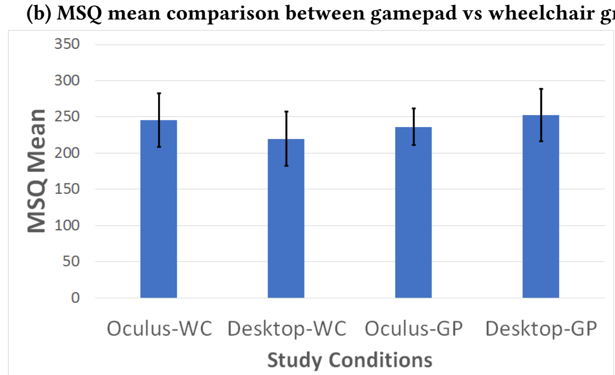
With two-way ANOVA, we found significant main effects of Display ($F(1,66) = 6.220$, $p = .015$, q partial $\eta^2 = .086$) and an interaction between Display and Interface $F(1,66) = 5.904$, $p = .018$, q partial $\eta^2 = .082$).



(a) MSQ mean comparison between immersive vs non-immersive group.



(b) MSQ mean comparison between gamepad vs wheelchair group.



(c) MSQ mean comparison among four conditions.

Figure 6: MSQ Score comparison for study participants. The whiskers represent standard deviation.

7.3.1 Display: Immersive vs Non-immersive. An independent-samples t-test was conducted to compare MSQ Score in the immersive and the non-immersive conditions (Figure 6a). We found a significant difference in the MSQ scores for immersive ($M=244.68$, $SD=29.70$) and non-immersive ($M=226.94$, $SD=35.08$) conditions; $t(68)=2.283$, $p = 0.026$.

These results suggest that the participants in immersive conditions were able to recall the information better than the participants in non-immersive conditions.

7.3.2 Comparing the Four Conditions. We also ran one-way ANOVAs on MSQ Score to compare the four conditions (i.e., Oculus-WC, Desktop-WC, Oculus-GP, and Desktop-GP) in our DS (Figure 6c).

We found a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 2.986, p = 0.037). Post hoc comparisons using the Bonferroni correction indicated that only the mean score for the Desktop-GP (M = 252.44, SD = 25.522) was significantly different (p < .05) than the Desktop-WC (M = 219.83, SD = 37.342).

7.4 Cybersickness Result (SSQ Score)

With two-way ANOVA on total cybersickness score, we found significant main effects of Display (F(1,66) = 41.77 p < .001 , q partial η^2 = .388) and an interaction between Display and Interface F(1,66) = 11.50, p ≤ .001, q partial η^2 = .148).

7.4.1 Display: Immersive vs Non-immersive. For post-hoc analysis, we ran independent-samples t-tests on different SSQ subscales (***nausea***, ***oculomotor***, and ***disorientation***) and also on ***SSQ total*** score between two groups based on display i.e., immersive and non-immersive.

For subscale ***nausea***, there was a statistically significant differences between group means as determined by t-test (immersive (M = 3.03, SD = 2.431) and non-immersive (M = 1.71, SD = 2.444) conditions; t(68) = 2.255, p = 0.027).

For subscale ***oculumotor***, there was a statistically significant differences between group means as determined by t-test (immersive (M = 6.03, SD = 3.996) and non-immersive (M = 2.74, SD = 3.221) conditions; t(68) = 3.787, p ≤ 0.001).

For subscale ***disorientation***, there was a statistically significant differences between group means as determined by t-test (immersive (M = 4.91, SD = 4.061) and non-immersive (M = 1.11, SD = 1.694) conditions; t(68) = 5.109, p ≤ 0.001).

For ***SSQ total***, there was a statistically significant differences between group means as determined by t-test (immersive (M = 13.97, SD = 9.454) and non-immersive (M = 5.57, SD = 6.946) conditions; t(68) = 4.236, p ≤ 0.001).

These results suggest that the participants in immersive conditions were more prone to cybersickness than the participants in non-immersive conditions.

7.4.2 Comparing the Four Conditions. We ran one-way ANOVAs on three subscales of SSQ score (***nausea***, ***oculomotor***, and ***disorientation***). These three subscales contributes to the scores of ***SSQ total***.

The subscale ***nausea*** did not show any statistically significant difference (F (3, 66) = 1.806, p = 0.155) among any of the group of two conditions taken from our four study conditions i.e., Oculus-WC vs Oculus-GP, Oculus-GP vs Desktop-WC etc.

For subscale ***oculumotor***, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 6.597, p ≤ 0.001). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-GP (M = 11.83, SD = 3.015) were significantly different (p < .05) than the Desktop-WC (M = 7.47, SD = 2.982).

For subscale ***disorientation***, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 10.245, p ≤ 0.001). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-GP (M = 5.94, SD = 4.789) were significantly different than both of the Desktop-WC (M = 0.89, SD = 1.132) and Desktop-GP (M = 1.35, SD = 2.149). Post hoc comparisons also indicated that the mean score for the Oculus-WC (M = 3.94, SD = 3.058) were significantly different (p < .05) than the Desktop-WC (M = 0.89, SD = 1.132).

For ***SSQ total***, there was a statistically significant difference between groups as determined by one-way ANOVA (F (3, 66) = 7.314, p ≤ 0.001). Post hoc comparisons using the Bonferroni correction indicated that the mean score for the Oculus-GP (M = 16.59, SD = 10.880) were significantly different (p < .05) than both of the Desktop-WC (M = 5.620, SD = 1.325) and Desktop-GP (M = 6.24, SD = 8.250).

Table 4: Descriptive statistics for SSQ.

Dimensions (p-value)	Oculus-WC Mean (SD)	Desktop-WC Mean (SD)	Oculus-GP Mean (SD)	Desktop-GP Mean (SD)
Nausea (0.155)	2.78 (2.533)	1.61 (2.227)	3.29 (2.365)	1.82 (2.721)
Oculumotor (≤ 0.001)	4.78 (3.021)	2.44 (2.662)	7.35 (4.541)	3.06 (3.783)
Disorientation (≤ 0.001)	3.94 (3.058)	0.89 (1.132)	5.94 (4.789)	1.35 (2.149)
SSQ Total (≤ 0.001)	11.50 (7.350)	4.94 (5.620)	16.59 (10.880)	6.24 (8.250)

8 DISCUSSION

8.1 Presence, Involvement and Flow in Immersive VR environment (H1 & H2)

The results from the PIFF^2 score suggest that users feel a higher sense of presence in immersive conditions (i.e., Oculus-WC and Oculus-GP) than in the non-immersive conditions. Similarly, the results from Moreno et al. [Moreno and Mayer 2002] - "users feel higher sense of presence with higher immersion i.e., when they use an HMD" agrees with our claim. Scores from another dimension of PIFF^2, Involvement, also suggests that in immersive conditions participants had more involvement with their VE than the non immersive conditions. This result also supports the claim that to experience presence, both involvement and immersion are necessary [Witmer and Singer 1998]. Based on the discussion, we can accept our hypothesis, **H1**.

One reason why participants who used an HMD had more presence and involvement in the VE is that there were almost zero external stimuli present from the outside world. The absence of any outside stimuli, gave the participants an environment where distraction was minimal, which might help them to immerse into the VE more. As a result of their undivided attention towards the VE, the sense of presence was higher. Moreover, participants were able to naturally rotate their head to view the VE and their avatar in the immersive conditions, which likely increased presence and involvement.

In $PIFF^2$, flow has two dimensions - "cognitive evaluation" which is related to challenge and skill, and "emotional outcome" which is related to enjoyment or boredom. In our study, for cognitive evaluation, we did not find any significant difference among the four conditions. This is an expected result as the tasks in our experiment involved low cognitive load. For example, in our VE users only had to navigate in a fixed path which is well defined; the path was nothing like a labyrinth, which would have had a higher cognitive load, for example. However, for the dimension emotional outcome, we did find significant difference in immersive and non immersive conditions which was rather interesting to look at and different from what we have expected. Our expectation was, as both Oculus-WC and Desktop-WC were using the wheelchair interface to navigate in the game, the emotional outcome would be higher for them than the participants who were in Oculus-GP condition who were using a gamepad to navigate.

We think the reason why the result was different than our expectation is that because participants who used Desktop-WC condition may have felt a disconnection between their interaction with the wheelchair and the display of the VE. That is, in Desktop-WC condition the virtual wheelchair was not visible because of the fixed camera position (Figure 1).

The wheelchair interface yielded higher $PIFF^2$ scores across dimensions of presence, involvement, and emotional outcome than the game-pad interface. This suggests that although it was inconclusive whether the wheelchair had an effect on information recall, it did have an effect on the overall subjective experience. We expect that this could potentially have an impact on empathy towards persons in wheelchairs. Thus, we do not have sufficient evidence to accept our hypothesis, **H2**. However, more research is needed to investigate this.

8.2 Cybersickness (H3)

SSQ questionnaire results from our study show a similar result to Sarah et al. [Sharples et al. 2008], where they compared display systems (i.e., HMD, desktop and projection display system) and found that HMD is more prone to induce the cybersickness than the other two display systems. We found a significant increase of total SSQ score when participants used an HMD. The same effect was found for two other subscales - oculomotor and disorientation. However, the subscale nausea did not show any significant difference. Previous research has found that cybersickness can be caused by the visually-induced perception of self-motion[LaViola Jr 2000]. In our study, the participants had to navigate in the VE. While navigating in the VE, the participants in two immersive conditions (i.e., Oculus-WC and Oculuc-GP) had minimal visual cues from the outside world. The movement participants noticed in the VE was using their virtual avatar as a reference, however, their physical body did not experience any movement. As the virtual movement required to navigate the VE was different than what their physical body was experiencing, it may have caused a conflict between their visual and vestibular systems. This conflict was likely the cause of the cybersickness experienced by the participants. However, for the participants in non-immersive conditions, sufficient visual cue were there to override any conflict in their brain that can cause them to feel cybersick. From the discussion above, we can see that the results from our study is aligned with our hypothesis, **H3**.

8.3 Effect of Presence on Information Recall (H4 & H5)

There was a significant correlation between presence and MSQ score (sec. 7.1). Moreover, results from the MSQ score suggest that in immersive conditions participants were able to recall the information more effectively than the participants in non-immersive conditions. This supports our hypothesis **H4** in that participants who experienced higher presence in immersive conditions were able to recall the information more correctly than the participants in the non-immersive conditions.

There are several potential reasons why this may have occurred. First, in both immersive conditions, the HMD gave a strong sense of presence of being "there" in VR. This increased sense of presence and the involvement in VE may have enabled the participants to concentrate more on the information that was presented. Another reason could be the unique experience participants had in immersive conditions where they could see their avatar in the virtual wheelchair from a first person perspective. This unique experience may have enabled them to connect with people with MS and remember facts about the people with MS more easily. Moreover, based on the "emotional outcome" results, there may be a potential relationship between immersion and the intention of disability simulations, which is to raise awareness and promote empathy. From the discussion above, we can see that the results from our study is aligned with our hypothesis, **H4**. However, more research is needed to confirm this.

We were unable to find any significant result to support our final hypothesis, **H5**. In our opinion, wheelchair alone was not enough to produce significant effect on the participants to help them on their information recall task. However, when wheelchair was conbined with an immersive HMD, the result was in favor of our hypothesis, **H4**.

8.4 Study Limitations

In this study, we were trying to find out the effect of presence on information recall in VR based DS, and also whether there are any adverse effect of cybersickness on information recall. However, due to the small sample size, it may not be the case that the results from our study is generalizable to all information recall tasks. Additional work is needed to generalize this to other disability simulations.

9 CONCLUSION AND FUTURE WORK

In this paper, we presented a between subject study that investigated the effects of immersive virtual environment displays and interfaces for one aspect of learning - information recall, in a disability simulation style environment. We investigate the effects oof display (i.e., immersive - HMD, non-immersive - Desktop monitor) and interface (wheelchair, game-pad) to understand the effect of the sense of presence, involvement and flow on information recall.

The results from our study suggest that participants who used an immersive HMD were able to achieve improved information recall than participants who used a desktop display. Although the interface had minimal effects on information recall, the wheelchair interface increased presence, involvement, and emotional outcome as compared to the game-pad. Our results also suggest that participants who were using HMDs experienced increased cybersickness. Despite the cybersickness, we found that the immersive VE induced a higher sense of presence, and enabled the participants to recall information more effectively .

In our future studies, we aim to evaluate the effect of the sense of embodiment on information recall. A full body tracking system could enable a stronger sense of embodiment and whether their higher sense of embodiment also leads to improved information recall. Additionally, we will further investigate other types of immersive displays and interfaces to understand their effects on learning.

We expect that with immersive VEs, disability simulation (DS) could be a helpful means to raise awareness and empathy towards persons with disabilities. In our future work, we plan to investigate how immersive VR-based DS affects people's attitudes and behaviors towards persons with disabilities.

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REFERENCES

EJ Arthur, PA Hancock, and ST Chrysler. 1997. The perception of spatial layout in real and virtual worlds. *Ergonomics* 40, 1 (1997), 69–77.

Jeremy N Bailenson, Nick Yee, Jim Blascovich, Andrew C Beall, Nicole Lundblad, and Michael Jin. 2008. The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *The Journal of the Learning Sciences* 17, 1 (2008), 102–141.

Barbara M Brooks. 1999. The specificity of memory enhancement during interaction with a virtual environment. *Memory* 7, 1 (1999), 65–78.

Chiu-Hsiang Chou. 1998. *The effectiveness of using multimedia computer simulations coupled with social constructivist pedagogy in a college introductory physics classroom.* Columbia University Teachers College.

Tanvir Irfan Chowdhury, Raphael Costa, and John Quarles. 2017a. Information Recall in a Mobile VR Disability Simulation. *9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)* (2017).

Tanvir Irfan Chowdhury, Raphael Costa, and John Quarles. 2017b. Information recall in VR disability simulation. In *3D User Interfaces (3DUI), 2017 IEEE Symposium on.* IEEE, 219–220.

Barney Dalgarno and Mark JW Lee. 2010. What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology* 41, 1 (2010), 10–32.

C DEDE and MC LOFTIN SALZMAN. 2001. Virtual realities for learning complex and abstract scientific concepts. 1995. (2001).

Ashley Flower, Matthew K Burns, and Nicole A Bottsford-Miller. 2007. Meta-analysis of disability simulation research. *Remedial and Special Education* 28, 2 (2007), 72–79.

Sally French. 1992. Simulation exercises in disability awareness training: A critique. *Disability, Handicap & Society* 7, 3 (1992), 257–266.

Richard D Hartwell. 2001. Understanding Disabilities. *Educational Leadership* 58, 7 (2001), 72–75.

Hannes Kaufmann, Dieter Schmalstieg, and Michael Wagner. 2000. Construct3D: a virtual reality application for mathematics and geometry education. *Education and information technologies* 5, 4 (2000), 263–276.

Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology* 3, 3 (1993), 203–220.

Joseph J LaViola Jr. 2000. A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin* 32, 1 (2000), 47–56.

Katerina Mania and Alan Chalmers. 2001. The effects of levels of immersion on memory and presence in virtual environments: A reality centered approach. *CyberPsychology & Behavior* 4, 2 (2001), 247–264.

Katerina Mania, Andrew Robinson, and Karen R Brandt. 2005. The effect of memory schemas on object recognition in virtual environments. *Presence: Teleoperators and Virtual Environments* 14, 5 (2005), 606–615.

Tassos A Mikropoulos and Antonis Natsis. 2011. Educational virtual environments: A ten-year review of empirical research (1999–2009). *Computers & Education* 56, 3 (2011), 769–780.

Roxana Moreno and Richard E Mayer. 2002. Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of educational psychology* 94, 3 (2002), 598.

MSQ 2017. Multiple Sclerosis Questionnaire (MSQ). (2017). Retrieved September 22, 2017 from https://goo.gl/L7oJ5t

OD 2017. Oxford Dictionary. (2017). Retrieved September 22, 2017 from https://en.oxforddictionaries.com/

Veronica S Pantelidis. 2010. Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education* 2, 1-2 (2010), 59–70.

Susan Persky, Kimberly A Kaphingst, Cade McCall, Christina Lachance, Andrew C Beall, and Jim Blascovich. 2009. Presence relates to distinct outcomes in two virtual environments employing different learning modalities. *CyberPsychology & Behavior* 12, 3 (2009), 263–268.

Sandra Dutra Piovesan, Liliana Maria Passerino, and Adriana Soares Pereira. 2012. Virtual Reality as a Tool in the Education. *International Association for Development of the Information Society* (2012).

Jayne Pivik, Joan McComas, Ian MaCfarlane, and Marc Laflamme. 2002. Using virtual reality to teach disability awareness. *Journal of Educational Computing Research* 26, 2 (2002), 203–218.

JIRI POLCAR and PETR HOREJSI. 2013. Knowledge Acquisition And Cyber Sickness: A Comparison Of VR Devices In Virtual Tours. *Science* (2013).

Joseph Psotka. 2013. Educational Games and Virtual Reality as Disruptive Technologies. *Educational Technology & Society* 16, 2 (2013), 69–80.

Eric D Ragan, Ajith Sowndararajan, Regis Kopper, and Doug A Bowman. 2010. The effects of higher levels of immersion on procedure memorization performance and implications for educational virtual environments. *Presence: Teleoperators and Virtual Environments* 19, 6 (2010), 527–543.

Ladette Randolph, Janet Murray, and Richard Lanham. 1998. Hamlet on the Holodeck: The Future of Narrative in Cyberspace. (1998).

Michael L Rothschild. 1984. Perspectives on involvement: current problems and future directions. *NA-Advances in Consumer Research Volume 11* (1984).

Maria Roussos, Andrew Johnson, Thomas Moher, Jason Leigh, Christina Vasilakis, and Craig Barnes. 1999. Learning and building together in an immersive virtual world. *Presence: Teleoperators and Virtual Environments* 8, 3 (1999), 247–263.

Maria Roussou, Martin Oliver, and Mel Slater. 2006. The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. *Virtual reality* 10, 3-4 (2006), 227–240.

Richard M Satava and Shaun B Jones. 1997. Virtual environments for medical training and education. *Presence: Teleoperators and Virtual Environments* 6, 2 (1997), 139–146.

Roger Schank and Henrietta Saunders. 2001. Virtual learning: A revolutionary approach to building a highly skilled workforce. (2001).

Sarah Sharples, Sue Cobb, Amanda Moody, and John R Wilson. 2008. Virtual reality induced symptoms and effects (VRISE): Comparison of head mounted display (HMD), desktop and projection display systems. *Displays* 29, 2 (2008), 58–69.

Ajith Sowndararajan, Rongrong Wang, and Doug A Bowman. 2008. Quantifying the benefits of immersion for procedural training. In *Proceedings of the 2008 workshop on Immersive projection technologies/Emerging display technologiges.* ACM, 2.

Kay M Stanney, Kelly S Hale, Isabelina Nahmens, and Robert S Kennedy. 2003. What to expect from immersive virtual environment exposure: Influences of gender, body mass index, and past experience. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 45, 3 (2003), 504–520.

Sharon Stansfield, Daniel Shawver, Annette Sobel, Monica Prasad, and Lydia Tapia. 2000. Design and implementation of a virtual reality system and its application to training medical first responders. *Presence: Teleoperators and Virtual Environments* 9, 6 (2000), 524–556.

Jonathan Stevens and Peter Kincaid. 2014. *Measuring Visual Displays' Effect on Novice Performance in Door Gunnery.* Technical Report. DTIC Document.

Jari Takatalo, Takashi Kawai, Jyrki Kaistinen, Göte Nyman, and Jukka Häkkinen. 2011. User experience in 3D stereoscopic games. *Media Psychology* 14, 4 (2011), 387–414.

William Winn. 1993. A conceptual basis for educational applications of virtual reality. *Technical Publication R-93-9, Human Interface Technology Laboratory of the Washington Technology Center, Seattle: University of Washington* (1993).

Bob G Witmer and Michael J Singer. 1998. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments* 7, 3 (1998), 225–240.

Zacharias C Zacharia. 2003. Using interactive simulations to enhance studentsâĂŹ explanations regarding physical phenomena. *Computer based learning* (2003).