Declarative Knowledge Acquisition in Immersive Virtual Learning Environments

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ABSTRACT

Motivated by a learners' general lack of engagement and passive receiving of information from lectures, and the increased use of interactive media from the millennial generation, the author investigated the interaction effect of immersive virtual reality (VR) in the classroom. The objective of the project was to develop and provide a low-cost, scalable, and portable VR system containing purposely designed and developed immersive virtual learning environments for the U.S. Army. The purpose of the mixed design experiment was to compare lecture-based and immersive VR-based multimedia instruction, in terms of declarative knowledge acquisition (i.e. learning) of basic corrosion prevention and control with military personnel. Participants were randomly assigned to the control group (N = 115) or investigational group (N = 25) and tested immediately before and after training. The author accessed learning outcomes from the pre- and post-exam scores and VR system usability from exit questionnaires. Results indicate that both forms of instruction will increase learning. VR-based did produce higher gain scores and there was a statistically significant interaction between instruction type and time. Lecture-based instruction continues to be a cheaper and more efficient method for large group settings while VR-based instruction advocates individual training, active learning, and condensed training time.

ABOUT THE AUTHORS

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INTRODUCTION

In 2009, total corrosion costs for the Department of Defense (DoD) alone were estimated at over 20 billion dollars a year (Herzberg, 2009). Naturally occurring, corrosion is often defined as the deterioration of a substance, usually a metal, or its properties because of a reaction with its environment (Committee on Assessing Corrosion Education, National Materials Advisory Board, Division on Engineering and Physical Sciences, & National Research Council, 2009, Jacobson, 2003). The ability to just discard and replace corroded assets with new ones has diminished as government continues to pass budget reductions. Now, the importance of educating soldiers on corrosion prevention and control (CPC) principles and theories has never been greater. Department of Defense (DoD) corrosion-related maintenance costs are estimated at over $23 billion each year, or approximately 40% of the defense system maintenance budget. These figures have pushed the DoD to implement CPC training programs of all types across the military branches (Corrosion Policy and Oversight Office, 2011). Currently, the form of instruction that is most commonly used is a PowerPoint® presentation accompanied by an instructor's lecture (i.e. lecture-based multimedia). This form of "brick and mortar" and "death by PowerPoint" instruction can be effective, but is passive and often unengaging and it does not capitalize on the learners' prior experiences (Headquarters Department of the Army, 2011). In 2011, the argument and suggestion to dramatically reduce or eliminate instructor-led digital slide presentations from the Army and begin using a blended learning approach of virtual and constructive simulations, gaming, and/or other technology-delivered instruction by 2015 was even proposed (Headquarters Department of the Army, 2011). This could significantly help attract and retain a younger generation of soldiers who have become more accustomed to using interactive technology and media not only for entertainment purposes but for education as well. There is a concern in the Army that not augmenting the existing classroom corrosion training with interactive immersive technology, such as virtual reality (VR) could be decreasing the military readiness and safety and providing suboptimal learning.

Defining VR and many of its associated features is difficult and often confusing. There can be a lot of crossover and grey areas within the reality-virtuality continuum, which consists of reality, augmented reality, mixed reality, and virtual reality (Milgram, Takemura, Utsumi, & Kishino, 1995). This also leads into VR as being a very interdisciplinary field. Mikropoulos and Strouboulis (2004) define VR as "a combination of high-end computing, human computer interfaces, graphics, sensor technology and networking which allows the user to become immersed in, interact, and experience in real time a three-dimensional (3D) artificial environment representing realistic or other situations" (p. 583), while Cobb and Fraser (2005) simply define it as a virtual environment (VE) with the means to access it. When the VE "is based on a certain pedagogical model, incorporates or implies one or more didactic objectives, provides users with experiences they would otherwise not be able to experience in the physical world, and redounds specific learning outcomes" (Mikropoulos & Natsis, 2011, p. 770) it is characterized as a virtual learning environment or educational virtual environment. Finally, according to Sartain (2012):

> The goal of VR technology is to enable the user to learn about or experience a target environment in a safe and controlled way that minimizes the costs associated with a hostile (e.g. battlefield), harsh (e.g. mine), specialized (e.g. cockpit), not readily accessible (e.g. distant tourist destination), or fantastical (e.g. imaginary) surrounding (p. 1)

Prior empirical research which has directly compared traditional instruction and immersive virtual learning environments (IVLE) has shown positive pedagogical value for IVLEs (Bowman, Hodges, Allison, & Wineman, 1999, Brelsford, 1993, Wang, 2012). Research has also shown that the use of VR in education can have a positive effect on learning (Bailenson et al., 2008, Bowman, Sowndararajan, Ragan, & Kopper, 2009, Trindade, Fiolhais, &

Almeida, 2002). Low cost VR hardware and software is now readily available to create safe and cost effective highly interactive educational training simulations that can produce almost instantaneous engagement for the learners and/or trainees (Bowman & McMahan, 2007, Dede, 2009). The Army believes that if treated "as an enabler, technology can be exploited to make learning content more operationally relevant, engaging, individually tailored, and accessible" (Headquarters Department of the Army, 2011, p. 12). After nearly two decades of research, IVLEs continue to be a promising educational training tool (Dede, 2009, Mikropoulos & Natsis, 2011) and education and training viewed as the possible killer markets for VR (Stone, 2002).

However, the magnitude of empirical research studies evaluating IVLEs that incorporate a head mounted display (HMD) as the main visual output device is low (Bailenson et al., 2008, Mikropoulos, 2006, Mikropoulos & Strouboulis, 2004, Salzman, Dede, Loftin, & Chen, 1999). Empirical research studies directly comparing outcomes from traditional lecture-based and VR-based multimedia instruction are even fewer (Bowman et al., 1999, Brelsford, 1993, Bryne, 1996, Crosier, Cobb, & Wilson, 2000, Wang, 2012), and no research has used an immersive (projection-based or HMD) VR for CPC training. Wang (2012) even states "no researchers explored the relationship between VR and traditional instructions in the past" (p. 422). The educational training benefits, learning outcomes, and effectiveness of VR, and IVLE usage in general also need to be examined further through rigorous scientific research (Dede, 2009, Lee & Wong, 2008, Mikropoulos, 2006, Ragan, Bowman, & Huber, 2012, Roussou, Oliver, & Slater, 2006). A top priority of the U.S. Army's is a well-trained force (Headquarters Department of the Army, 2002). This implies not only battle tactics and operating procedures, but the basic acquisition of declarative knowledge on a wide-range of topics. One question that remains is will the integration of immersive VR with purposely built IVLEs into existing CPC training further help force readiness and increase learning outcomes. In this study, we addressed that question.

The purpose of this study was to compare the routine classroom instructor-led training (i.e. lecture-based multimedia instruction) and immersive VLE training (i.e. VR-based multimedia instruction) in terms of learning, of basic CPC theories and principles, in U.S. Army soldiers after taking an U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office (CPO) CPC training course. Additionally, specific subjective features of the IVLE, such as ease of use, ease of learning, user comfort, likability, acceptability, and satisfaction, were evaluated. The trainees present for each training course were randomly assigned to either the control or investigational group and tested immediately before and after training. The manipulation of instruction type allowed access to the effects on learning outcomes. The author analyzed learning from the pre- and post-exam scores and VR system usability from exit questionnaires. The following research questions were proposed: how does CPC learning compare between lecture-based and immersive VR-based multimedia instruction and what is the usability of the VR system used?

METHOD

Participants

Pre-registered trainees (N = 140) from 14 individual routine AMCOM Corrosion Program CPC training courses over six states participated in this study. Participants included active and reserve duty U.S. Army soldiers who are normally classified as maintainers of aviation assets.

The convenience sample for the research study consisted of 140 participants (four females) with a mean age of 29.64 and median age of 28.00 years (SD = 8.03), range 19 to 59. Of which, 32.14% (N = 45) had previously attended an AMCOM CPC course, 68.57% (N = 96) had previously heard of VR, and 21.43% (N = 30) had prior experience(s) with immersive VR (most often flight and driving simulators). Using a five-level Likert scale (1 = never/none; 5 = always/extremely), the sample as a whole was somewhat to moderately familiar with CPC (M = 3.27) and computers and/or smart phones (M = 3.86), often to always use computers and/or smart phones (M = 4.41), sometimes to often play video games (M = 3.29), and none to slightly familiar with VR (M = 1.95). Table 1 presents the characteristics of the two subsamples.

Table 1. Demographic characteristics of subsamples (in percentages).

Characteristic	Lecture-based (control group)	VR-based (investigational group)
N	115	25
Participant Age (years)		
M	29.50	30.32
Mdn	28.00	30.00
SD	8.04	8.09
Range	20-59	19-50
Participant gender	Male (97)	Male (100)
Participant history		
Previously attended an corrosion course	38 (33)	7 (28)
Previously heard of VR	80 (70)	16 (64)
Prior immersive VR usage	25 (22)	5 (20)

Materials

An instrument search revealed no currently available questionnaires or exams that could measure the variables for this research study. Materials varied according to the group's instruction type. The two groups are described in the following paragraphs.

Control

Participants in this group were given an entrance questionnaire, pre-exam, and post-exam. The instruction type consisted of an instructor from the AMCOM CPO delivering a lecture accompanied by a digital multimedia presentation. The setting was a typical classroom or conference room (tables, chairs, digital projector, etc.).

The entrance questionnaire obtained participants general background information, demographic characteristics, and information concerning inclusion and exclusion criteria. The question types were closed-ended (e.g. yes/no/unsure and scaled), open-ended (e.g. sentence completion), and contingency. Analysis and scoring of each entity and response were separate (i.e. not summed).

The objective of the exams was to provide a means for assessing learning in terms of general declarative knowledge acquisition. They consisted of 22 questions, of which six were multiple answer and 16 were multiple choice. Questions 1-16 had four possible answer choices while questions 17-22 had six. The post-exam had five different questions than the pre-exam (17 common exam questions) and shuffled order.

Corrosion subject matter experts and instructors from the AMCOM CPO provided face and content validity for the exams. Test-retest reliability testing proved to be unfeasible, largely due to the inability to gain access to the same soldiers twice over a period of two-four weeks.

There were five different exam topics, which permitted the methodically grouping of the exam questions. The number of questions under each topic is not equal because the training delivered to all participants was divided unequally in the amount of information and the actual training time across the five exam topics. The five topics are as follows: the importance of CPC, corrosion basics, corrosion influences, corrosion types, and basic corrosion prevention. Finally, the exam questions aligned with the following six learning objectives.

1. Demonstrate their knowledge of why CPC is important by identifying and selecting the outcomes of past lack thereof.
2. Demonstrate their knowledge of corrosion by *identifying* and *selecting* characteristics of the definition.
3. Demonstrate their knowledge of the mechanics of corrosion by *identifying* and *selecting* the individual components of corrosion and possible influences.
4. Demonstrate their knowledge of *identifying* different types of corrosion by *selecting* each type.
5. Demonstrate their knowledge of different types of corrosion by *identifying* and *selecting* characteristics of each type.

6. Demonstrate their knowledge of basic CPC techniques, theories, and principles.

Investigational

Participants in this group were given the same entrance questionnaire and exams as the control group. They also completed two exit questionnaires after training. The instruction type consisted of an immersive VR system containing three purposely designed and developed IVLEs. The setting was the same as the control group for questionnaires and exams; however the participants received their training in various locations and conditions across the research sites. Some were of the classroom nature while others were in spare offices and locker rooms.

The first exit questionnaire given evaluated the VR systems usability (e.g. visibility, tracking, interaction, etc.), VLE content, and various subjective measures (e.g. engagement, satisfaction, comfort, ease of use, ease of learning, etc.). The questions were closed-ended (e.g. yes/no/unsure, scaled, and multiple choice). Analysis and scoring of each entity and response was separate (i.e. not summed). The second exit questionnaire contained six open-ended questions and was more exploratory and seeking of central themes.

After researching commercially available VR hardware and software and through a thorough selection process, the Wirks™ (Schlueer, 2012) VR bundle by WorldViz® (http://www.worldviz.com/) was choosen. It provided an affordable solution for stereoscopic 3D viewing and user tracking in a COTS package. The Sony® HMZ-T1™ was the HMD that provided the participants with immersive stereoscopic 3D viewing while performing the interactive simulations. User tracking (e.g. position and orientation) was accomplished through a combination of a Microsoft Kinect® for Windows® (http://www.microsoft.com/en-us/kinectforwindows/) and an Inertial Labs® sub-miniature 3D orientation sensor (OS3D) (Inertial Labs Inc., 2012). Interactions (e.g. travel, selection, manipulation, and system control) within the IVLE were performed through tracked body movements by the Kinect® and participant input using a Bluetooth® Zeemote® JS1 controller (http://www.zeemote.com/).

The VR toolkit used was Vizard™ (http://www.worldviz.com/products/Vizard) by WorldViz®, which was included in the Wirks™ VR bundle. Vizard™ was utilized in creating and controlling the IVLE content and integrating all the various hardware pieces. Bridging the Kinect® data and Vizard™ was FAAST™ (http://projects.ict.usc.edu/mxr/faast/), which was the open-source middleware that enabled the full body control and tracking of the interactive simulations.

Participants of the investigation group performed interactions (e.g. travel, selection, manipulation, system control, etc.) within three different IVLEs (i.e. usage and training module one and two), which all consisted of the same base VR world (see Figure 1). The VR world was populated with 3D geometry, such as a moving platform, movie screen, and animated pedagogical agent (i.e. embedded autonomous agent). Top priority during design was to increase the possibility of interaction, entertainment, engagement, and provoking emotion from the participants while fostering increased learning.

Figure 1. Scene used for all three IVLEs. *Note*. Egocentric view

Each IVLE consisted of a combination of active and passive media. Passive media pertained to audio listening, image viewing, and video watching while active media pertained to interactive gameplay. The two types of gameplay were action shooter trivia (see Figure 2) and jigsaw puzzles (see Figure 3). The goal of the action shooter trivia game was to correctly shoot the answer(s) to the corrosion-based trivia question (14 total questions). The goal of the jigsaw puzzle game was to correctly select and manipulate the individual pieces into place, to display the full high resolution image of that type of corrosion (7 total types).

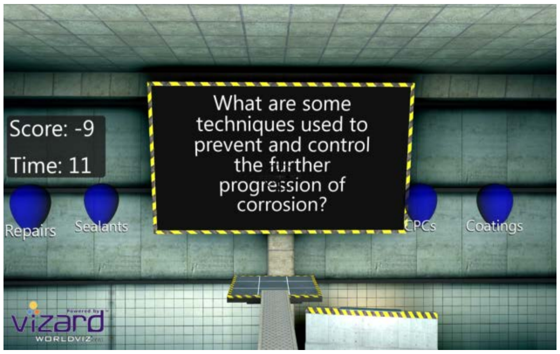

Figure 2. Action shooter trivia. *Note*. Egocentric

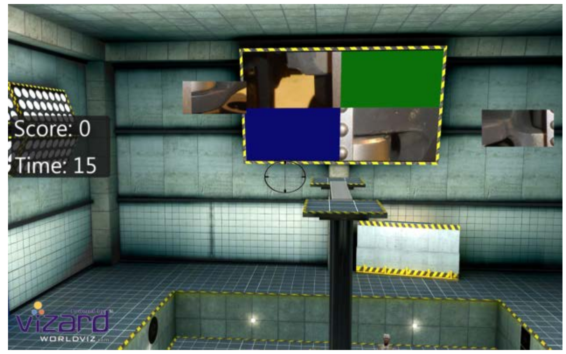

Figure 3. Jigsaw puzzle. *Note*. Egocentric view

Designs

When designing the IVLEs, Dr. Richard Mayer's cognitive theory of multimedia learning (see Figure 4) for how people process information from multimedia messages (i.e. learning with technology) was adapted.

For the mixed design experiment, the categorical between-participant independent variable was the type of multimedia instruction (two levels). The second categorical independent variable was the within-participant factor of time, which correlated with subjecting the participants to the repeated measures (i.e. pre- and post-exams). The continuous dependent variable of learning outcome was measured for each group across each condition of the repeated measure. The scoring differentials (i.e. gain scores) between exams was also explored. Finally, the study evaluated the VR system's ease of use, ease of learning, user comfort, likability, acceptability, and satisfaction. A combination of t-test, chi-square test, one-way analysis of covariance (ANCOVA), and mixed (between-within) analysis of variance (ANOVA) was used to analyze the data.

Procedures

From June 2013 to November 2013, coordination with the AMCOM CPO on the 14 research sites took place. The CPO controlled the location, order, and research's access to the routine CPC training courses. The commanders at each research site controlled the number of students in attendance for each course. There are eight Instructors at the CPO and normally two attend each training site. The CPO also controlled which instructor(s) attended each site and who performed the lecture-based multimedia instruction. The CPC training courses can take place anywhere in the world. However, all research sites were located within the contiguous United States at active and reserve duty U.S. Army installations.

For tracking and correlation purposes, each participant in both groups created a unique identifier when signing their

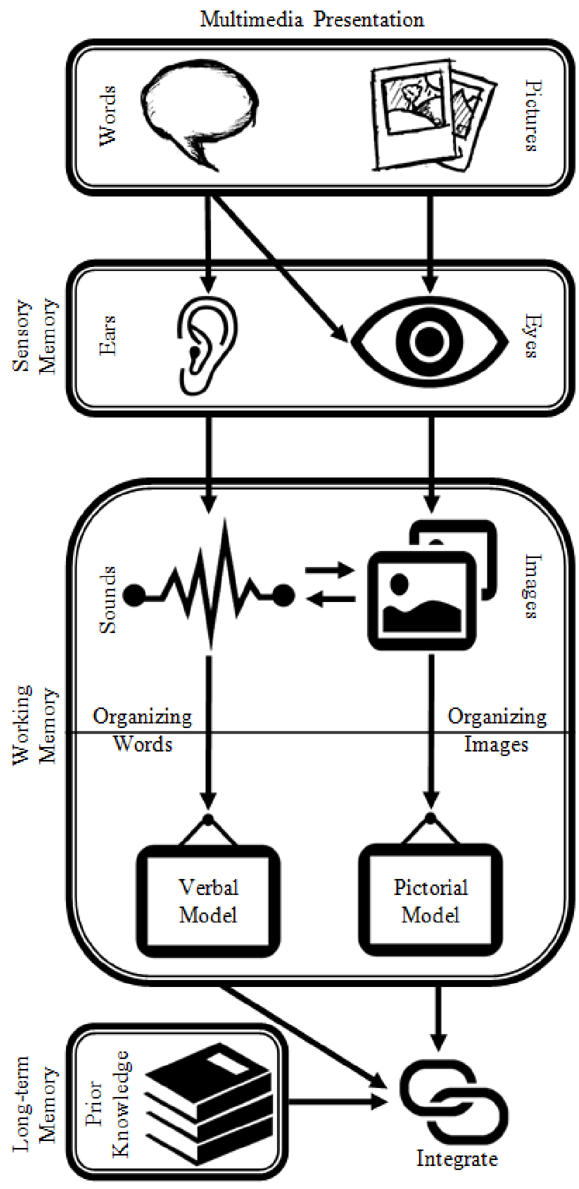

Figure 4. Cognitive theory of multimedia learning. *Note*. Adapted from (Mayer, 2009)

consent form. They then proceeded to write it on each instrument (e.g. questionnaires and exams) that they completed (i.e. filled out).

The first IVLE that the participants trained in was the usage module. Here they became familiar with the VR system, had the HMD properly fitted, achieved optimal tracking, took part in activities that would later be seen and/or used in training module one and two, and asked questions as needed. The second IVLE was training module one (action shooter trivia) and third was training module two (jigsaw puzzle). Each IVLE took approximately 15±5 minutes.
I repeated the general procedural steps below as needed to reach the target sample size for the investigational group, which was originally set at >20.

1. Before the start of the CPC training course, the author placed a manila envelope, containing a copy of the informed consent and entrance questionnaire at each student's seat.
2. While delivering a short presentation concerning the general details of the research study the students reviewed the instruments and decided on if they would like to volunteer. If so, they signed the consent form, completed the entrance questionnaire, and placed them back into the manila envelope.
3. After collecting all the envelopes, the author differentiated the volunteers (i.e. participants) from non-volunteers by signed consent forms and fully filled out questionnaire.
4. I distributed the pre-exam to only participants who met the inclusion criteria (i.e. 19 years of age or older, while the remaining of the students (i.e. non-volunteers) waited. Once the students finished the author collected all the pre-exams.
5. While the pre-exam was being administered the author entered all the unique identifiers from the consent forms into a random number generator and selected (i.e. randomly assigned) one or two participants to the investigational group based on class size and time constraints. The author then analyzed their individual entrance questionnaires to ensure they met the inclusion and exclusion criteria. If not, the author would place that participant into the control group and then randomly generate another participant for the investigational group. This process continued as needed.
6. As the control group continued with the lecture-based multimedia instruction the investigational group began the VR-based multimedia instruction in a separate location. Only one VR system was available so only one participant at a time completed the training.
7. Once each participant of the investigational group completed all three IVLEs (e.g. usage and training modules one and two), the exit questionnaires were completed.
8. Once all the participants from both groups received instruction (i.e. training), they reconvened to take the post-exam.

RESULTS

Independent samples *t*-tests were conducted to compare the entrance questionnaire mean scores between the groups' participants. Between the two groups there was no significant difference in scores on any of the measures (see Table 3). Chi-square tests of independence were conducted to examine the entrance questionnaire frequency responses between the groups' participants. The relation between group type and each measure was not significant (see Table 3). An independent samples *t*-test was conducted to compare the pre-exam scores (only 17 common exam questions) between the groups' participants. There was no significant difference in score between the two groups, $p = .501$.

Table 2. Group analysis by study instruments.

	p
***t*-tests: Entrance questionnaire mean scores**	
Familiarity: CPC	.959
Familiarity: computers/smart phones	.895
Familiarity: VR	.591
Usage: computer/smartphones	.504
Usage: video games	.706
Chi-square tests: Entrance questionnaire frequency responses	
Previously attended CPC course	.698
Previously heard of VR	.836
Previously used immersive VR	.771

A one-way ANCOVA was conducted for this research study. The independent variable, type of multimedia instruction, included two levels: lecture-based and VR-based. The dependent variable was the participants' post-exam scores (only 17 common exam questions) and the covariate was the participants' score on the pre-exam (only 17 common exam questions). A preliminary analysis evaluating the homogeneity-of-regression (slopes) assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1, 136) = .33$, $p = .568$. The ANCOVA was significant, $F(1, 137) = 7.61$, $p = .007$.

Learning

The control groups' mean exam score increased by 11.17% (22 exam questions) and 11.45% (17 common exam questions) respectively after the lecture-based multimedia instruction (see Table 2). The investigational groups' mean exam score increased by 26.20% (22 exam questions) and 18.47% (17 common exam questions) respectively after the VR-based multimedia instruction (see Table 2). The majority of the sample showed an increase in mean score from pre-exam to post-exam (17 common exam questions), however, 15.71 percent ($N = 22$) of the sample showed a decrease. Only one of the 22 belonged to the investigational group.

Table 3. Exam scores by multimedia instruction type.

Exams	Lecture-based (control group)	VR-based (investigational group)
Pre-exam (17 common questions)		
M	65.26	66.91
Mdn	63.64	68.18
SD	11.41	9.51
Range	36.36-90.91	40.91-86.36
Post-exam (17 common questions)		
M	72.73	79.27
Mdn	72.73	77.27
SD	10.73	10.98
Range	45.45-95.45	50.00-95.45

A mixed between-within participants ANOVA was conducted to compare exam scores (only 17 common exam questions) between the lecture-based and VR-based multimedia instruction participants across two time periods (i.e. pre-exam and post-exam). There was a statistically significant interaction between instruction type and time, Wilks' Lambda = .97, $F(1, 138) = 3.94$, $p = .049$, partial eta squared = .03. There was a significant main effect for time, Wilks' Lambda = .68, $F(1, 138) = 64.74$, $p < .001$, partial eta squared = .32, with both group participants showing an increase in exam scores across the two time points (see Table 3 and Figure 5).

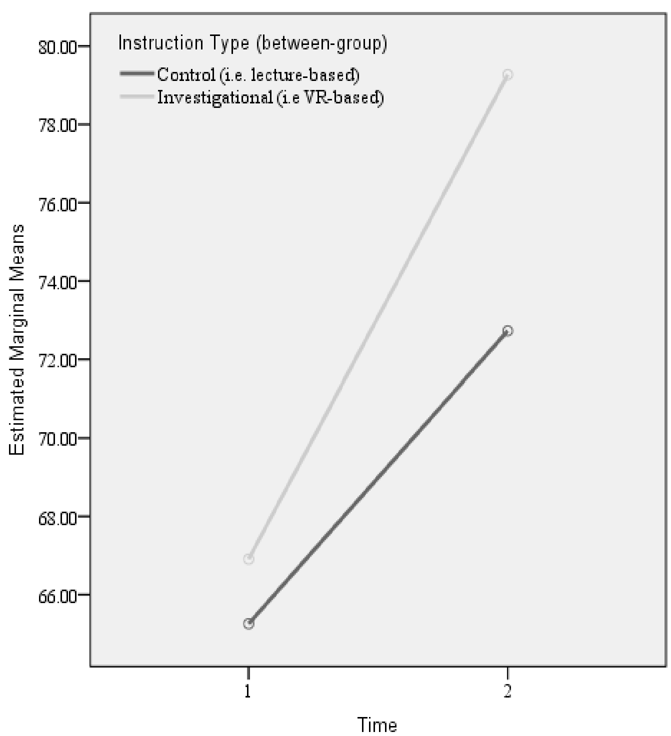

Figure 5. Interaction plot - 2 x 2

Usability Evaluation

Participants of the investigational group ($N = 25$) provided the usability evaluation. Eighty-eight percent believed that an IVLE was an efficient method of training for CPC. Seventy-two percent would like additional training sessions in the IVLE. Seventy-two percent would prefer a learning environment, for CPC training; of a combination of classroom lecture-based and VR-based multimedia instruction.

Common themes, based on participant's feedback from the open-ended questions, were as followed:

1. The IVLEs provided more immersive and engaging training.
2. The equipment was slightly uncomfortable and tracking could be improved.
3. The IVLEs shortened overall training time while introducing a more individual training experience.

DISCUSSION

These results are consistent with those of other studies (Bailenson et al., 2008, Brelsford, 1993, Trindade et al., 2002), which suggest that the higher levels of immersion (Bowman et al., 2009), engagement, interaction, and motivation that the immersive VLEs provided over instructor-led lectures resulted in the increased learning for the investigational group. The author also speculates that the combination of actively engaging multiple participants' senses (i.e. sight and hearing) while providing an alternative to the highly overused digital presentation in military educational training contributed to the groups' success.

This study agrees with the results found by Bowman et al. (1999) who suggests that a combination of instruction techniques is more effective than traditional education alone. In fact, 72 percent of the participants who received the VR-based instruction would prefer so. In general, the combination of instruction types would allow for a greater range of learning styles. Consistent with Mikropoulos, Katsikis, Nikolou, and Tsakalis (2003) immersive VLEs will continue to be a valuable educational tool. However, stakeholders must also be aware of not allowing the novelty of the technology to overshadow its true purpose in the classroom.

A future aim of using VR-based multimedia instruction alongside lecture-based is to enable more effective learning because it can shorten training time and possibly increase long-term retention of knowledge and skills (Sadagic, 2007). As Brelsford (1993) put it, "VR allows the educational task to become much more intuitive; information is passed between the environment and the student with increased efficiency and selectivity" (p. 1287). Other affordances of VR include increasing the trainees' motivation to train and learn, providing safer and less costly training scenarios, and viewing phenomenons unable to be seen by the human eye (Sadagic, 2007). In summary, according to the Headquarters Department of the Army (2011):

> They provide training events that are highly compressed in time, simulate environments that cannot be replicated in live training, can be tailored to the learners' level of knowledge, can ramp up complexity and stress on demand, allow multiple repetitions to increase mastery, and have advantages of accessibility and adaptability. (p. 23)

No matter how great VR technology becomes it will never be able to fully replace an instructor in the classroom. A limitation of most immersive VR systems is the possible number of trainees concurrently receiving the instruction. For large group settings not only is lecture-based instruction generally more cost effective but also more efficient. Screen resolution and human ergonomics will continue to improve for immersive VR while costs and consumer resistance will continue to decrease. However, if VR does continue to grow in popularity and continued scientific research shows positive impacts to the education process, pedagogy, and training, educators and trainers will have to take notice and begin adapting.

There were limitations to this study. One limitation was that it did not control for variability between each control group instructor used at each research site. Another potential limitation was that only U.S. Army soldiers aged 19-59 years of age, with the majority being labelled as aviation maintainers, made up the sample. Basic corrosion prevention and control was also the only subject area used for this study. Further research is needed with an upgraded VR system and on other training courses that have an aspect of general declarative knowledge acquisition. Finally, this study explored learning in a time frame of minutes and hours. Research conducted on long-term retention (i.e. weeks and months) after VR use continues to be an area of much needed empirical research. There are very few published studies and most just do not have the sample sizes needed to provide validity.

ACKNOWLEDGEMENTS

The U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office needs to be recognized for their support and expertise. Intuitive Research and Technology Corporation was instrumental in the completion of this research. Specific individuals that deserve acknowledgment are Steve Carr, Courtney Guasti, CPC training team, graduate committee (extra gratitude to Dr. Killen and Dr. Snyder), Vergenia Shelton, Amanda Clark, Rey Almodovar, and Hal Brewer.

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