CORROSION PREVENTION AND CONTROL TRAINING IN AN IMMERSIVE VIRTUAL LEARNING ENVIRONMENT

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INTERDISCIPLINARY ENGINEERING

ABSTRACT

The majority of military education and training has not veered far from the days of *chalk and talk* instruction. Often with technological breakthroughs comes the proposal of the next revolution in multimedia instruction. Motion pictures to radios to educational television programs have all seemed to come and gone. The next wave of multimedia learning may involve more than a PowerPoint® presentation and lecture. Researchers continue to propose that Virtual Reality (VR) will find its true application and/or market in education and training.

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 (VLE). The purpose of the research study was to empirically compare the routine classroom instructor-led training and immersive VLE training in terms of learning and long-term retention of basic Corrosion Prevention and Control (CPC) knowledge 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. Usability evaluation of the VR system was also included.

The immersive VLEs were a better form of multimedia instruction in terms of learning for basic CPC theories and principles than instructor-led lectures with PowerPoint. In terms of learning there was a statistically significant interaction between instruction type and time, Wilks’ Lambda = .97, $F(1, 138) = 3.942, p = .049$. In terms of
long-term retention, there was no significant interaction between instruction type and time.

Keywords: corrosion, immersive virtual learning environment, learning, long-term retention, training
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LIST OF ABBREVIATIONS

2D  two-dimensional
3D  three-dimensional
AHRPO  Army Human Research Protections Office
AMCOM  Aviation and Missile Life Cycle Management Command
CAVE  CAVE Automatic Virtual Environment
COTS  Commercial Off-The-Self
CPC  Corrosion Prevention and Control
CPO  Corrosion Program Office
DoD  Department of Defense
EVE  Educational Virtual Environment
FOR  Field Of Regard
FOV  Field Of View
HMD  Head Mounted Display
UAB  University of Alabama at Birmingham
VE  Virtual Environment
VLE  Virtual Learning Environment
VR  Virtual Reality
INTRODUCTION

Motivation

Individuals and industries very often fear change. Often because of the failure or the success that may result from that change. The Army on the other hand cannot risk failure by resisting change (Headquarters Department of the Army, 2011). The first motivational factor for performing this research study is the general belief that existing corrosion educational training will be improved by complementing it with immersive Virtual Reality (VR). The past has shown that applications for VR are vast, and many have not shown the promises as originally proclaimed. However, education/training continues to be viewed as the possible killer market/application for VR (Stone, 2002). Performing this research study provided an unique opportunity to explore the impacts to U.S. Army soldiers’ learning and long-term retention outcomes by implementing immersive and interactive technology into their existing training, which engages and incites the users’ imagination. In doing so, the anticipation was to discover a training enhancement for the U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office (CPO).

As military equipment and infrastructure continue to grow old, the fight against corrosion continues to escalate. In 2009, total corrosion costs for the Department of Defense alone were estimated at over 20 billion dollars a year (Herzberg, 2009). 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 the
soldiers on Corrosion Prevention and Control (CPC) principles and theories has never been greater. Currently, the form of multimedia instruction that is most commonly used is a PowerPoint presentation accompanied by an instructor’s lecture (i.e. lecture-based multimedia). This form of multimedia instruction has proven to be effective in the past, but most soldiers have now become more accustomed to interactive digital technology and media for not only personal entertainment but also education/training. In 2011, the argument/suggestion to dramatically reduce or eliminate instructor-led lecture-based multimedia instruction (i.e. slide presentation) 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). Therefore, the second motivational factor in performing this research study was to investigate if augmenting the existing corrosion training with immersive VR (i.e. extension) would help engage, entertain, and/or provoke emotion in the students while fostering increased learning and long-term retention. In a report by the Headquarters Department of the Army (2011):

The Army must close this gap to attract and retain a generation of young people who know how to use technology to learn both formally and informally. The Army must leverage technology to establish a learning system that provides engaging, relevant, and rigorous resident, distributed, and mobile learning. (p. 11)

Statement of Problem

Twenty three billion dollars and 40% of the defense system budget each year to fight corrosion related costs has forced the Department of Defense (DoD) to implement
CPC training programs of all types (Corrosion Policy and Oversight Office, 2011). The U.S. Armed Forces have actively implemented a number of research and development initiatives and training strategies to prevent, detect, predict, treat, and control corrosion, which continues to be an ever increasing cost and safety burden for the military (Corrosion Policy and Oversight Office, 2011). Much of the training involves classroom instructor-led education using a traditional educational method consisting of 2D multimedia, print documentation, and lectures (Larsen, 2008, Scully & Harris, 2012). “Passive, lecture-based instruction does not engage learners or capitalize on prior experience” (Headquarters Department of the Army, 2011, p. 7). Using only this form of instruction could potential lead to a loss of trainee engagement as well as suboptimal learning and long-term retention (Chris Dede, 2009, Mayer, 2005, D. L. Schwartz & Bransford, 1998). There is a concern that not augmenting the existing training with interactive immersive technology, such as VR could be decreasing military readiness and safety.

Prior empirical research directly comparing traditional lecture-based multimedia instruction versus Virtual Learning Environments (VLE) or Educational Virtual Environments (EVE) has shown positive pedagogical value for VLEs (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, Yee, et al., 2008, Bowman, Sowndararajan, Ragan, & Kopper, 2009, Trindade, Fiolhais, & Almeida, 2002) and long-term retention (Bowman et al., 1999). 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, Chris Dede, 2009). “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, VLEs continue to be a promising educational training tool (Chris Dede, 2009, Mikropoulos & Natsis, 2011).

However, the magnitude of empirical research studies evaluating VLEs that mainly used a Head Mounted Display (HMD) for user immersion is low (Bailenson, Yee, et al., 2008, Mikropoulos, 2006, Mikropoulos & Strouboulis, 2004, Salzman, Dede, Loftin, & Chen, 1999). Empirical research studies directly comparing 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) VLE for CPC training. The educational training benefits, learning outcomes, and effectiveness of VR, and VLE usage in general also need to be examined further through evaluative research (Chris Dede, 2009, Lee & Wong, 2008, Mikropoulos, 2006, Ragan, Bowman, & Huber, 2012, Roussou, Oliver, & Slater, 2006). Long-term retention of knowledge is also possibly the most important characteristic of VLEs that is in need of research due to the scarcity (Mikropoulos & Natsis, 2011, Ragan, Sowndararajan, Kopper, & Bowman, 2010). With the U.S. Army’s top priority being training (Headquarters Department of the Army, 2002). The integration of a VLE into existing CPC training performed by the AMCOM CPO could further help force readiness and safety.
Purpose Statement

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 and long-term retention of basic CPC theories and principles in U.S. Army soldiers after taking an AMCOM CPO’s CPC training course. Additionally, specific subjective features of the immersive VLE, such as ease of use, ease of learning, user comfort, likability, acceptability, and satisfaction, were evaluated.

Research Questions

The research study focused on finding answers to the following research questions:

1. How does learning of basic CPC theories and principles compare between lecture-based multimedia instruction and multimedia instruction using immersive VLEs for the U.S. Army?

2. How does long-term retention of basic CPC theories and principles compare between lecture-based multimedia instruction and multimedia instruction using immersive VLEs for the U.S. Army?

3. What is the usability (i.e. ease use, ease of learning, user comfort, likability, acceptability, and satisfaction) of the VR system?

By evaluating the results to the above questions, I hoped to be able to convey to the AMCOM CPO the highest quality of information so that they can make an informed decision.
Hypotheses

The following null and alternative hypotheses were defined for the formal research study:

$H_0$: An interaction is absent

$H_1$: An interaction is present

Significance of the Study

This research study instantly contributes to the fields of VR, education, training, multimedia, and corrosion by adding to their respective knowledge bases. If the VR system receives, final approval and integration into the AMCOM’s CPOs existing curriculum takes place it will help improve their CPC training practices. The literature review exposed the need for additional research studies because of the following:

- Empirical research studies directly investigating VLEs and long-term retention are almost nonexistent.

- There was a significant lack of empirical research directly comparing lecture-based and VR-based multimedia instruction.

The literature review also exposed the need for a research study because of the following:

- Immersive VLEs have yet to be empirically studied within the corrosion field.

- The VR system used in this study had previously not been used in any published research study.
It should also be noted that this research study was performed alongside existing real world training and used the potential future users of the VR system as the research study participants. This along with performing a true experiment is often uncommon to find in VR research.

Definitions of Terms

The following definitions are provided to ensure uniformity and understanding of these terms throughout the study. The researcher developed all definitions not accompanied by a citation.

*Active Media*. Pertaining to media (i.e. training material/content) that allows the user to be actively engaged, such as interactive simulations.

*Agent*. “Models driven by computer algorithms” (Bailenson, Yee, et al., 2008, p. 105).

*Animated Pedagogical Agent*. On-screen agent that helps guide the learner/trainee through the interactive simulation (Mayer, 2010). *Embedded autonomous agent, – syn.*

*Avatar*. “Models driven by humans in real time” (Bailenson, Yee, et al., 2008, p. 105).

*CAVE*. An immersive display system where images are projected on three or more large display screens that surround the human participant (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992).

*Corrosion*. “Corrosion is the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment” (National Association of Corrosion Engineers, 2011, pp. 1-1).
Declarative Knowledge. “Refers to our memory for concepts, facts, or episodes” (McNamara & O'Reilly, 2003, p. 1432).

Educational Virtual Environment. See virtual learning environment

Egocentric. “A frame of reference that provides a view of an object, space, or phenomenon from within” (Chris Dede, 2009, p. 66).

Exocentric. “A frame of reference that provides a view of an object, space, or phenomenon from the outside” (Chris Dede, 2009, p. 66).

Fidelity. Pertaining to a computer simulation is the extent to which the VE correctly responds to the user’s actions (Hintze, Schumann, & Stuering, 2000).

Field of View. “The total size of the visual field (in degrees of visual angle) surrounding the user” (Bowman & McMahan, 2007, p. 38).

Field of Regard. “The size of the visual field (in degrees of visual angle) that can be viewed instantaneously” (Bowman & McMahan, 2007, p. 38).

Gustatory. Pertaining to the sense of taste.

Haptic. Pertaining to the sense of touch.

Head Mounted Display. Computer graphics equipment that is worn on the head which is a complex integration of electrical, optical, mechanical, and audio components that provide 2D or 3D viewing through either one (monoscopic) or two (stereoscopic) display feeds close to the user’s eyes (Bowman, Kruijff, LaViola, & Poupyrev, 2005).

Head-based Rendering. “The display of images based on the physical position and orientation of the user’s head (produced by head tracking)” (Bowman & McMahan, 2007, p. 38).
**Immersion.** “Refers to the objective level of sensory fidelity a virtual reality system provides” (Bowman & McMahan, 2007, p. 38).

**Immersive.** See immersion

**Information Gathering.** The act of obtaining information from or about the VE while in it (Bowman, 2002).

**Information-rich Virtual Environment.** “An EVE that provides both experiential and abstract information in a tightly coupled manner” (Bowman et al., 1999, p. 318).

**Input Device.** “A physical device allowing communication from the user to the computer” (Bowman et al., 2005, p. 6), such as a joystick or wand.

**Instruction.** “Is the manipulation of the learner’s environment by the instructor(s) in the order to foster learning” (Mayer, 2010, p. 188). Pedagogy, teaching, educating, and training – syn.

**Interactive Simulations.** “Simulations over which the learner has some control, such as being able to slow down and animation or set input parameters and observe what happens” (Mayer, 2010, p. 181).

**Knowledge Acquisition.** “The process of absorbing and storing new information in memory, the success of which is often gauged by how well the information can later be remembered, or retrieved from memory” (McNamara & O'Reilly, 2003, p. 1431).

**Learning.** “Is a long-lasting change in the learner’s knowledge attributable to the learner’s experience” (Mayer, 2010, p. 183).

**Long-term Retention.** Pertaining to remembering after a period of weeks.

**Multimedia.** “Instruction that consists of picture (such as illustrations, photos, animation, or video) and words (such as printed or spoken text)” (Mayer, 2010, p. 181).
**Multimedia Learning.** Building mental representations through multimedia (Mayer, 2005, p. 2).

**Multimedia Instruction.** Presenting multimedia that is intended to promote learning (Mayer, 2005, p. 2). *Multimedia learning environment – syn.*

**Non-immersive.** Pertaining to VR systems that do not have the ability to block out the majority of the real world, cannot present content in life size, and/or the level of immersion is low or unattainable, such as desktop VR.

**Olfactory.** Pertaining to the sense of smell.

**Output Device.** “A physical device allowing communication from the computer to the user” (Bowman et al., 2005, p. 6), such as a screen or projector.

**Passive Media.** Pertaining to media (i.e. training material/content) that allows the user to be a passive recipient, such as video watching, imaging viewing, and audio listening.

**Presence.** “Refers to an individual user’s subjective psychological response to a virtual reality system” (Bowman & McMahan, 2007, p. 38) and is often associated with a sense of *being there.*

**Readiness.** As defined in United States General Accounting Office (2003): Generally defined as a measure of the Department of Defense’s ability to provide the capabilities needed to execute the mission specified in the National Military Strategy. At the unit level, readiness refers to the ability of units, such as Army divisions, Navy ships, and Air Force wings, to provide capabilities required of the combatant commands. (p. 1)
**Remembering.** “Is the ability to reproduce or recognize the presented material, and is assessed by retention tests” (Mayer, 2005, p. 13). *Recall – syn.*

**Serious Games.** “Games that are intended to serve an instructional function” (Mayer, 2010, p. 181).

**Stereoscopy.** “The display of different images to each eye to provide an additional depth cue” (Bowman & McMahan, 2007, p. 38).

**Tactile.** Pertaining to the sense of touch.

**Usability.** As defined in Blade and Padgett (2002a):

The effectiveness, intuitiveness, and satisfaction with which specified users can achieve specified goals in particular environments, particularly interactive systems. Effectiveness is the accuracy and completeness of goals achieved in relation to resources expended. Intuitiveness is the learnability and memorability of using a system. Satisfaction is the comfort and acceptability of using a system. (p. 25)

**Virtual Environment.** As defined in D'Cruz (1999):

Computer-generated representations of real or imaginary environments, experienced as three dimensional via a number of sensory channels. Objects within these environments are independent of the user and can display real world behavior. The user has autonomous control - the freedom to navigate and interact with the objects. This interaction occurs in real-time and the users experience feelings of presence and/or involvement. (p. xix).

**Virtual Learning Environment.** “A virtual environment that 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).

Virtual Reality. “Virtual reality is 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” (Mikropoulos & Strouboulis, 2004, p. 583), or simply encompasses a VE along with the means to access it (Cobb & Fraser, 2005).

VR Toolkit. Software that creates the virtual environment architecture, the placement and assigning of behaviors of objects (e.g. CAD models, avatars, etc.) within, and the user’s allowable interactions (Cobb & Fraser, 2005).

Limitations and Delimitations

The CPO controlled the location, order, and research’s access to the routine CPC training courses. The personal 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.

Data collection during the formal research study stopped when the investigational group reached 25 participants for reasons of funding (i.e. travel costs) and time constraints.

An instrument search revealed no currently available questionnaires or exams that could measure the variables for this research study. Therefore, I developed all the instruments (see Materials section and APPENDIX B). I did however reference
instruments from published research when possible (Brough, 2006, Kabala, 2011, Kaewkuekool, 2003, McMahan, 2007, 2011, Paul, 2010). Graduate study committee requested test-retest reliability testing; however, it proved to be unfeasible, largely due to the inability to gain access to the same soldiers twice over a period of two-four weeks.

The significant drop in completed long-term retention exams (see Long-term Retention Outcome section) is because there was a) no further face-to-face contact between the researcher and participant, b) no enticements (e.g. gifts, payment) given, c) no orders by participant’s commanding officer to complete the exam, d) lack of required computer skills needed, e) technical difficulties, f) etc. I could not control items a-d however, I preformed numerous trial runs of sending, receiving, opening, and completing the long-term retention exam to minimize possible technical issues. I ensured that various email clients could receive the email and various internet browsers could open the exam link. Any emails that were bounced when sent were investigated and a correction to the email address was made or a secondary email address for the participant was found (i.e. AKO DoD Enterprises White Pages) and used. To increase response rate I also sent a reminder email approximately one week after the initial email.

The population for the research study was military personal because these are typically the students, which attend the CPC training courses. The U.S. Army labels the vast majority of the sample as maintainers. Training modules for the VR-based multimedia instruction with other topics (i.e. other than CPC) were not developed. This is the direct result of the AMCOM CPO funding the majority of the research study.

The results of this study can be generalizable to enlisted U.S. Army personal who a) maintain aviation assets, b) are aged > 18, and c) are active or reserve duty.
Assumptions

It was assumed that during this study:

1. Participants’ gender, geographical location, and/or job title would not significantly affect their perceptions.

2. Participants would answer all questionnaire items and exam questions honestly and to the best of their ability.

3. Participants would give their full attention and effort to no matter which type instruction they received.

4. Participants would remain in either training for the complete period (i.e. pre-exam to post-exam exam taking).

5. The CPC instructors would conduct their lecture-based multimedia training in the same fashion as if no research study was taking place.

6. Each CPC instructor would generally provide the same (e.g. topics covered, contact time, etc.) lecture-based multimedia training.

Dissertation Roadmap

The following section presents a review of related literature and research pertaining to the major topics of VR, VR for educating, and corrosion, which are a focal point of the study. The next section contains details on the methodology, including design, materials, and procedures for this study. The results and findings from the data analysis are presented next. The final section contains conclusions drawn from the findings, discussion about the results, and recommendations for further work.
LITERATURE REVIEW

Literature Search

I searched for and retrieved the pieces of literature from numerous indexed databases through the University of Alabama at Birmingham’s (UAB) Mervyn H. Stern Library website. As I surveyed and analyzed the literature, their respective bibliographies were also examined for further perspective pieces of literature, which often lead to individual searches through the Internet and/or e-journals. The various pieces of literature surveyed were journal articles, conference papers, conference proceedings, books (e.g. textbooks, handbooks, and novels), magazine articles, electronic articles, government documents, and technical reports. For the detailed reviews (i.e. critiques) of the literature provided in the various sections below, I tried to use only peer reviewed empirical journal articles. Although limited, some of the sections do reference and/or contain a detailed review of a piece of literature from other than a peer reviewed journal, such as published conference papers and proceedings, book chapters or sections, government documents, technical reports, and magazine articles. The most cited journals are Presence: Teleoperators & Virtual Environments, Virtual Reality, Computers & Education, Education and Information Technologies, British Journal of Educational Technology, and IEEE Transactions on Visualization and Computer Graphics.

Concerning the characteristics of the current study, I deemed it important to find and provide a detailed review of all peer reviewed empirical journal articles that contained the phrases *educational virtual environment* or *virtual learning environment*
and head mounted display. Based on previous knowledge and Mikropoulos and Natsis (2011) recent review article on EVEs and VLEs the following major databases were targeted a) ERIC (ProQuest), b) JSTOR, c) OCLC ArticleFirst, d) IEEE, e) Science Direct (Elsevier), f) SpringerLink, g) Wiley, h) ACM Digital Library, i) Academic Search Premier (EBSCO), j) Education Full Text (EBSCO), k) Taylor & Francis, and l) PubMed. I did not apply a limited date range during the searches because of the relatively young age of VR research, or was it necessary that UAB always had full text access as I used Interlibrary Loan as needed.

The literature was divided along four general topic areas of a) VR (e.g. history and applications), b) VR for educating, c) traditional education vs. VR (e.g. lecture-based vs. VR-based multimedia instruction), and d) corrosion (e.g. training/education and learning tools and techniques).

Virtual Reality

Defining VR just like many fields of study, such as mechanical engineering or computer science can be complicated. VR can mean many different things and be very difficult to define. Someone could say they work or research in the field of VR when really they could be more precise and say 3D user interfaces or augmented reality. This also leads into VR as being a very interdisciplinary field. In simple terms, VR technology is used for various applications for the purpose of enabling 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 (Sartain, 2012).
The term VR was coined and/or popularized in the early 80s by Jaron Lanier, who also cofounded VPL Research, Inc., which became famous for creating some of the first consumer grade VE equipment (Blade & Padgett, 2002b). Most notably U.S. Patent #4,542,291, the DataGlove (Zimmerman, 1985) and EyePhone. However, VR history does not really begin there. It was early science fiction literature that sparked the imaginations of inventors to try to recreate these artificial or illusory environments with technology. Science fiction literature has even coined and/or popularized some of VRs most used terms, such as “cyberspace” from Neuromancer (Gibson, 1984) or “avatar” from Snow Crash (Stephenson, 1992).

Burdea and Coiffet (2003) describe VR as an integrated trio of immersion, interaction, and imagination (i.e. the three I’s of VR). Probably the first VR device that encompassed all three I’s was Morton Heilig’s Sensorama, which received U.S. Patent #3,050,870 in 1962 (Heilig, 1962). It was an immersive 3D experience that had motion, color, stereo sound, aromas, wind effects, and a vibrating seat (Burdea & Coiffet, 2003). Heilig also received U.S. Patent #2,955,156 for a HMD that supported stereo sound and an odor generator (Heilig, 1960). Heilig’s HMD is often viewed as one of the first HMDs created, however the first probably goes to the Philco Corporation in 1961 (Blade & Padgett, 2002b, Gupta, Anand, Brough, Schwartz, & Kavetsky, 2008).

The 1960s and 1970s continued to see significant advancements in VR and computer graphics. One of the most notable would be in 1963 when Ivan Sutherland’s published his dissertation at MIT on the first interactive computer graphics system, named Sketchpad (Sutherland, 1963). He followed with research on HMDs and created what is commonly referred to as the Sword of Damocles. A mechanically supported
HMD using two cathode ray tubes mounted along the user’s ears (Sutherland, 1968). Burdea and Coiffet (2003) statement below demonstrates the imaginative vision of Dr. Sutherland, something that Fredrick Brooks would make reality in 1971 at the University of Carolina at Chapel Hill:

> Sutherland’s vision of an “ultimate display” to the virtual world was not limited to graphics. In 1965 he predicted that the sense of touch (or haptics) would be added in order to allow users to feel the virtual objects they saw. (p. 5)

The 1970s and 1980s saw the military eager to develop flight helmets and modern simulators, however much of the work was classified at did not become available until defense cuts forced some of the researchers to migrate into the civilian sector (Burdea & Coiffet, 2003). The Super Cockpit flight simulator built in the early 80s by Thomas Furness (Furness, 1986, 1988) was just as monumental in flight training as the Link Flight Trainer was in 1920s and 30s (De-Angelo, 2000). The term artificial reality was coined in 1973 by Myron Krueger, who was studying the artistic and psychological aspects of VR at the University of Wisconsin (Blade & Padgett, 2002b). VR in the 80s also saw an increase in popularity from motion pictures, such as Star Wars, The Last Starfighter, Blade Runner, and The War Games. Some of the first true consumer-grade VR hardware also came out during the decade, such as the above mentioned DataGlove and the PowerGlove developed for Nintendo Home Entertainment (Blade & Padgett, 2002b).

Up until the early 1990s the market of immersive VR was dominated by HMDs (Gupta et al., 2008) and VR systems/demos for flight and driving simulations (Brooks, 1999). Then the researchers at the Electronic Visualization Laboratory at the University
of Illinois, Chicago created a projector-based display system called the CAVE™, which stood for CAVE Automatic Virtual Environment (Cruz-Neira et al., 1992). Now, many of the worlds most pronounced research labs and centers of excellence use CAVEs to achieve the highest levels of user presence. It was around this time that the public and various professional industries started to notice VR and its potential. This even lead to the organizing of the first major international conferences concerning VR, such as Interfaces for Real and Virtual Worlds (1992, Montpellier, France), Medicine Meets Virtual Reality (1992, San Diego, CA), and IEEE Research Frontiers in Virtual Reality (1993, San Jose, CA), which is now known as IEEE VR (Burdea & Coiffet, 2003). One final invention to note was the creation of Virtual Reality Modeling Language (VRML) (designed specifically for the World Wide Web), which now permits the easy development of a plethora of VR applications (Blade & Padgett, 2002b).

The above examples may give the impression that VR continued to prosper into the 21st century without any downfalls or negative publicity (see Figure 1). However, Stone (2008) recognizes the mistakes of early VR:

From the perspective of potential adopters throughout many commercial sectors (including defense and medicine), VR delivered a roller coaster ride of achievement and failure throughout the 1990s. Factors such as commercial naivety on the part of VR companies, significant failures to deliver meaningful and usable intellectual property on the part of so-called academic “centers of excellence”, expensive and unreliable hardware, an absence of case studies with cost-benefit analyses and a widespread absence of attention to the requirements and limitations of the end users, all took their toll by the end of the 1990s. (p. 1)
Today, VR researchers and developers still have major challenges to address. Low cost, user friendly, readily available, low latency, high resolution, lightweight, wide field of view consumer grade HMDs still do not fully exist. The Oculus Rift by Oculus VR™ (http://www.oculusvr.com/) and the HMZ-T1™ and -T2 by Sony® are two recent examples of HMDs heading in the right direction that are worthy of mentioning. Tracking (e.g. gesture, gaze, positional, etc.), haptics (i.e. force feedback), and 3D user interfaces (e.g. omni-direction treadmills, controllers, etc.) devices are still maturing. The first awarded patent (U.S. Patent #5,562,572) for an omni-directional treadmill, which could be the answer to true realistic and immersive locomotion within a VE, was in 1996 (Carmein, 1996). Almost two decades later, there is still not an affordable commercially available omni-directional treadmill. The Omni by Virtuix (http://www.virtuix.com/) may change that. More sophisticated means of getting the information from the body to the electronics needs to be developed (Blade & Padgett, 2002b). Physical (e.g. user comfort, etc.) and cognitive (e.g. sociability, immersion, engagement, etc.) ergonomics will need to be improved (Gross, 2002). Even the simple idea of incorporating more of the human
senses besides just sight and hearing, such as taste, smell, and touch could possibly produce a more immersive and realistic experience. In 2008, the National Academy of Engineers released a list of 14 grand challenges for engineering. Enhance VR made the list (National Academy of Engineering, 2012). Finally, the following three questions are based on Bowman et al. (2005) list of three million-dollar questions concerning 3D user interfaces:

1. Can the real benefits of VR technology be quantified?
2. Will VR ever be standardized?
3. What will be the killer application/market for VR?

Applications for Virtual Reality

Over the last decades, VR has moved out of the military’s grasp and even the VR research laboratories to several application domains, where it has become a useful tool (Gervasi & Ranon, 2010). Today, VR technology, often immersive VR have applications in the fields of:

Military/Defense. Small unit close combat/infantry (Muller, 2010); virtual maintenance for modern weapons systems (McMaster et al., 2002); mission preparation, rehearsal, and training (Kneer, Breaux, & Goldberg, 2002, Tate, Sibert, & King, 1997)

Medical. Disorder treatment (e.g. posttraumatic stress, anxiety, addictions, obesity, etc.) (Bordnick, Carter, & C., 2011, Reger et al., 2011, Rizzo et al., 2011); skill training (e.g. mass casualty triage) (Vincent, Sherstyuk, Burgess, & Connolly, 2008); therapy/rehabilitation (e.g. strokes, burns, phobias, etc.) (Bowman & McMahan, 2007, Maani et al., 2008, Weiss, Naveh, & Katz, 2003); anatomical learning (Luursema, Verwey, Kommers, Geelkerken, & Vos, 2006); surgery (Bowman et al., 2005)
Architectural/Engineering/Product Design. Architectural design review and walk-throughs (Mobach, 2008); assembly and disassembly operations (M. Schwartz, Gupta, Brough, Anand, & Kavetsky, 2007); automotive (e.g. ergonomics, styling, design, etc.) (Baron, 2009)

Training/Education. Aircraft maintenance (Buck & Perrin, 2004, Vora et al., 2002); spatial/navigation (Waller, Hunt, & Knapp, 1998); skill, performance, and/or knowledge transfer (Kenyon & Afenya, 1995, Lathan, Michael, Sebrechts, Clawson, & Higgins, 2002, Rose et al., 2000); martial arts (Chua et al., 2003); operations/procedures (Sowndararajan, Wang, & Bowman, 2008); see Virtual Reality for Educating section and Lotens and Riemersma (1997) for additional details

Visualization. Volume data (e.g. 3D medical images, geophysical exploration, computer aided design, datasets, etc.) (Laha, Sensharma, Schiffbauer, & Bowman, 2012, Schuchardt & Bowman, 2007); art (Bowman et al., 2005, Keefe, Feliz, Moscovich, Laidlaw, & LaViola, 2001)

Entertainment. Games, theme parks, sports, movies, etc. (Badique et al., 2002, Perez, 2012)

The following statement by Salvendy (2002), which is possibly from the most comprehensive text on VR to date should reinforce just how far VR has come:

The field of virtual environments (VEs) emerged some 40 years ago as a very exotic, extremely expensive technology whose use was difficult to justify. The discipline has matured, and the cost of VE technology has decreased by over 100-fold, while computer speed has increased by over 1,000 fold, which makes it a
very effective and viable technology to use in a broad spectrum of applications, from personnel training to task design. (p. xi)

Virtual Reality for Educating

I ordered the critiqued literature concerning VR for educating into four major themes a) EVE/VLE, b) edutainment, c) learning, and d) long-term retention. Within the major theme of EVE/VLE, there were two major subthemes of immersive and non-immersive. Within the major subtheme of immersive, there were two minor subthemes of projection and HMD. Many of the articles researched and/or mentioned characteristics of learning (e.g. concepts, facts, knowledge, memorization, etc.) and/or learning theories (e.g. cognition, constructivism, situated learning, exploratory learning, etc.). This could have allowed categorization under numerous themes. However, since the current research is using immersive VLEs and a HMD to explore learning and long-term retention outcomes, I gave top priority for article ordering to those characteristics. I also realized that the various articles surveyed presented research, which could have been interpreted as using a VLE, but unless the author(s) clearly stated so within the literature, it was either ordered elsewhere or ignored.

Educational Virtual Environments / Virtual Learning Environments

There is still no single killer application or market for VR, but for decades, researchers have advocated that education and training would be areas of growth and prosperity for VR (Stone, 2002). Starting as early as 1990 and continuing through the 90s there are mentions of using VR for learning purposes, however these first instances are mostly arguing for the potential usefulness of the technology as an educational tool (M.
Bricken, 1991, W. Bricken, 1990, Hedberg & Alexander, 1994, Helsel, 1992, Pantelidis, 1993, Winn, 1993, Winn & Jackson, 1999). “Since then, a number of research articles have appeared reporting on the design, development, and evaluation of EVEs concerning a variety of disciplines and different educational levels” (Mikropoulos & Bellou, 2006, p. 123). A more recent and very thorough review article is by Mikropoulos and Natsis (2011). Many of the reviewed studies are concerned with the learners’ ability to learn, acquire knowledge, and/or the mastery of abstract concepts in what the VR research field call EVEs or VLEs, which are commonly used interchangeably. Mikropoulos and Bellou (2006) propose the following features of a EVE/VLE that contribute to positive learning outcomes: free navigation, first – person point of view, natural semantics, size, transduction, reification, autonomy, and presence. In a different manner, Dalgarno and Lee (2010) present five learning affordances of VLEs:

1. “3-D VLEs can be used to facilitate learning tasks that lead to the development of enhanced spatial knowledge representation of the explored domain” (p. 18).
2. “3-D VLEs can be used to facilitate experiential learning tasks that would be impractical or impossible to undertake in the real world” (p. 19).
3. “3-D VLEs can be used to facilitate learning tasks that lead to increased intrinsic motivation and engagement” (p. 20).
4. “3-D VLEs can be used to facilitate learning tasks that lead to improved transfer of knowledge and skills to real situations through contextualization of learning” (p. 21).
5. “3-D VLEs can be used to facilitate tasks that lead to richer and/or more effective collaborative learning than is possible with 2-D alternatives.” (p. 23)
Predictions and theories are a starting point, but before a new technology can become an effective educational tool, the educators and instructors, who will be utilizing VLEs must deem them as acceptable and favorable. A survey study by Taylor and Dasinger (1997) was one of the first empirical studies on the acceptance of VR in education, specifically environmental education. The authors proposed three research questions a) what is the current level of acceptance of VR as a teaching tool in environmental education by environmental educators, b) what are perceived as the most beneficial roles and applications of VR to the field of environmental education, and c) what areas concerning the application of VR to environmental education should be studied in order for VR to become an effective tool in environmental education? The systematic sample was 400 environmental educators from a membership list provided by the North American Association for Environmental Education (NAAEE) and 40 VR developers and programmers that volunteered from an Internet posting. Mailed surveys collected the participant’s responses. Of the 192 received completed surveys the authors used descriptive statistics and chi-square test to analyze the data. The principal findings were that VR is looked at as an acceptable educational tool by environmental educators and the notion that a VLE can provide the student or trainee with experiences unallowable in the physical world. Also noted is the belief that VR technology will likely be available in the education community in 10 to 20 years and if so, it will force educators to reevaluate traditional teaching and learning methods.

Non-immersive

The majority of VLEs that have been empirically researched are desktop VR systems (Bakas & Mikropoulos, 2003, Barnett, Yamagata-Lynch, Keating, Barab, &

1. The ability to block out the real world is very limited
2. The VR content cannot be presented in life size
3. The level of immersion is low or unattainable

A rudimentary mixed method study by Mikropoulos, Chalkidis, Katsikis, and Emvalotis (1998) investigated students’ attitudes toward VLEs and towards VLEs in specific disciplines. The two hypotheses were a) there is a positive acceptance of VR in the educational process and b) students prefer the joystick as the most effective input device for navigation in virtual environments (VE). The convenience sample was 20 students (16 female) who volunteered from the Department of Primary Education at the University of Ioannina, Greece for the first VLE study and 14 of the original 20 also participated in using the second VLE. The age range was 18 to 26 and 70% were above 21 years of age. Both studies used an entrance questionnaire concerning demographics, previous experience in information technologies, type of computer use, and level and
source of information about VR. Additionally, after experiencing either VLE the participants filled out an open and closed ended questionnaire and had discussions concerning their experiences. Descriptive statistics was used in both studies to give the participants’ subjective measures on previous computer use, attitudes towards information technologies, expressions after their first VLE experience, attitudes towards the second VLE ($N=11$), and attitude towards the input devices ($N=11$). The results show a positive attitude towards VR in the education process, specifically for participants who are studying to be future teachers. Concerning the attitude towards input devices for navigation in VLEs the mouse was clearly preferred over the more sophisticated peripherals made for 3D environments. This could be because the VLEs were non-immersive and utilized desktop VR technology.

“VR has revolutionized how people of all ages learn and work. However, there has been few studies that investigate individual differences in the use of VR” (Lee, Wong, & Fung, 2010b, p. 79). Lee et al. (2010b) performed a study which investigated the effects of a desktop VLE on learners with different learning styles. The categorization of the learning styles were based on the Kolb Learning Style Inventory, which also helped form the hypotheses. The four were a) no significant difference in the performance achievement for accommodator learners and assimilator learners, b) no significant difference in the overall improvement in performance for accommodator learners and assimilator learners, c) no significant difference in the perceived learning effectiveness for accommodator learners and assimilator learners, and d) no significant difference in the perceived satisfaction for accommodator learners and assimilator learners. The sample from which data was analyzed on was 210 science students (122
females) from four randomly selected co-education secondary schools in East Malaysia, which have started to learn biology (original sample was 232). At each school one to three intact classes were randomly chosen and the age range was 15 to 17 (meap 16). Summative scores from a pretest and posttest measured a students’ academic performance and questionnaires subjectively measured perceived learning effectiveness and satisfaction (also collected background information). The desktop computer software program V-Frog provided the training material. There was also a two week delay between pretest and posttest taking. Data analysis was completed using a combination of descriptive statistics and independent sample $t$-tests. The major findings from the study were “no significant difference in the performance achievement, overall improvement in performance, perceived learning effectiveness and satisfaction between accommodator learners and assimilator learners in the VR-based learning environment” Lee et al. (2010b, p. 88). The findings help the argument that one of the main features of VR is that it can benefit learners of all learning styles.

**Immersive**

In keeping with the focus of the current research, which uses immersive VLEs, a study by Livantino, Muscato, and Previtera (2009) on the usability of different display technologies was reviewed. The purpose of the study was to analyze performance improvement when using stereoscopic vision on seven different VR systems in a mobile robot teleguide context. The two research questions were a) will stereo viewing be advantageous for indoor workspaces and b) how will performance vary when using seven different display technologies? A within-subject experiment containing aptitude, interactive, and comparative conditions took place. The participants had varying
backgrounds and age, and had either no or moderate experience with computer games and VR technology. The aptitude experiment had 14, interactive 10, and comparative 24 participants respectively. The quantitative measures for the aptitude and interactive experiments were sensor measurements, user inputs, and specific process simulations gathered through the VR software, which resulted in users’ performance estimates. Questionnaires gathered the subjective data in the comparative experiment. One-way analysis of variance (ANOVA) analyzed the data from the aptitude and interactive experiments. Through descriptive statistics analysis the user subjective parameters of adequacy to application, realism, presence, 3D impression, and comfort in the comparative experiment were analyzed. Livantino et al. (2009) found that no VR system performs best for all applications and portability is an important consideration. No matter, stereo viewing allowed improvements in many areas of navigation and the study gives future VR system designers a baseline of VR system attributes to consider.

Projection. To subdivide the immersive section further, I categorized the following pieces of literature by the display technology primarily used: projection (e.g. CAVE, workbenches, display walls, or domes) or a HMD. Generally, projection technology and HMDs allow for a higher level of immersion and a higher likelihood of presence. However, there is a lack of empirical research done on the benefits of immersion for abstract mental activities, such as conceptual learning. Even less research on what features of immersive VR are beneficial for learning (both process and outcomes) in educational applications.

Ragan et al. (2010) had the purpose of investigating the effects of immersion on procedure memorization and to determine which components and characteristics of the
VR system effected conceptual learning outcomes. They hypothesized that greater performance in procedure memorization tasks would be the result of higher levels of immersion benefiting the mental activity of mapping objects or locations in the VLE. The convenience sample consisted of 36 participants down selected from the 41 original volunteers because of initial memory tests scores. Participants had a mean age of 22 and gender breakdown of 11 female and 25 male. A demographic questionnaire also measured video game experience \( (N = 18) \) and prior immersive VR experience \( (N = 8) \).

The six between-subject conditions had equal participants and average scores on initial memory test. The dependent variables measured were the number of errors in the memorization procedure and time to complete the steps. Time and error data analysis used mixed ANOVA method and comparison of the six conditions used post hoc Turkey tests. Shown through empirical evaluation, a higher level of immersion does improve abstract mental activity performance and so does an increase in field of view (FOV) and field of regard (FOR). It was also shown that high end immersive VR systems, such as the three wall CAVE that was used for all six conditions does not have to be used over slightly lower immersive and less costly VR technologies (e.g. HMD) to achieve optimal performance.

Another research study utilizing a CAVE is by Limniou, Roberts, and Papadopoulos (2008). The authors are investigating if a VLE can provide an alternative medium for teaching chemistry education because of the concern that traditional tools and language that teachers are using are not providing optimal results or motivation to learn. The purpose was to compare the independent variable of teaching tool, 2D chemical animations designed for a desktop computer or 3D chemical animations in a
VLE using a CAVE to see if student learning increased. No direct research questions or hypotheses are given. The convenience sample was 29 college chemistry participants (14 in the 2D group and 15 in the 3D group) from Eccles College of Salford University in the United Kingdom. The only details given on data collection were a four question multiple-choice exam to evaluate learning and a discussion session for the CAVE group participants to evaluate student’s attitudes towards using the VLE. Analysis of the dependent variable of learning used ANOVA method. Discussion sessions reviled that generally the CAVE raised student’s interest and motivation to learn by presenting them with the phenomenon of being inside the chemical reactions and facing 3D molecules, which is not possible in the physical world. The other major finding was that the ANOVA revealed that the CAVE participants scored higher on all four of the multiple-choice questions.

What actually constitutes an effective VLE for conceptual learning is not known, especially for children (Roussou et al., 2006). This research problem was the driving force behind Roussou et al. (2006) study that had the purpose of trying to provide analytical evidence of learning in an immersive VLE versus a non-immersive environment as a result of interactivity, and explaining what forms of interaction introduced the learning. The authors defined interactivity as the ability to freely navigate through a VLE, experience it first hand from multiple points of view, and to modify, control, and respond to elements of the VLE. The research question was how does interactivity in VLEs influence learning? A pilot and exploratory study took place before the formal experiment with 57 primary school students between the ages of eight and 12 to define the evaluation methodology and improve the usability of the VLE. The
convenience sample for the formal experiment was 25 females and 25 males from different schools and demographic backgrounds. There were three conditions for the between group formal experiment, which were interactive immersive VLE, passive VLE (embodied autonomous agent), and non-immersive environment using LEGO™ bricks each with an even spread to age and gender. Instruments used to collect data were a) entrance questionnaire for profiling of computer familiarity, frequency of computer game play, and prior experience with VR, b) direct observations, c) interviews, d) video, audio, and log files, and e) pre- and post-exam questionnaires with questions related to arithmetical fractions. “The quantitative analysis showed no meaningful association between the different variables, such as gender, age, and condition, on student performance (measured through the pre- and post-tests)” (Roussou et al., 2006, p. 235). The authors present only selected portions of the qualitative data in the article and it was inductive analyzed to give forth three themes a) problem of comparing fractions, b) response to system feedback, and c) substituting the denominator. The interactive immersive VLE did not aid conceptual change, however the passive VLE condition appeared to support student reflection and recall through the qualitative data.

“It is important to investigate the educational efficiency of VR in specific learning situations and broader learning domains, and to develop new rubrics of educational efficacy that compare it to other approaches” (Roussos et al., 1999, p. 254). However, the majority of the evaluations of the first two decades of VR technology have focused on usability. Roussos et al. (1999) investigated how their immersive VLE titled Narrative-based, Immersive, Constructionist/Collaborative Environments (NICE) effected the overall educational efficiency based on some of the current educational reform themes
(e.g. constructionism, exploratory learning, collaboration, and primacy of narrative).

NICE provides children with an immersive, interactive, and exploratory VLE, which supports children’s learning of simple relationships between plant, growth, sunlight, and water. No direct research questions or hypotheses are given. The convenience sample was 52 children with 44 second-grade students (26 female) from an urban elementary school with an ethnically mixed population and the remanding eight from other area schools. The instruments used were observations, open-ended interviews, and entrance questionnaire concerning technology experience, familiarity with gardening, and understanding of simple ecological concepts. To analyze the data the authors developed a general evaluation framework that had six categories/themes a) technical, b) orientation, c) affective, d) cognition, e) pedagogical, and f) collaborative VR. Based on the observation data the authors were able to propose four general criteria for future research concerning VLEs a) the learning goal must be important, b) the learning goal must be hard, c) the learning goal must be plausibly enhanced by the introduction of immersive VR technologies, d) VLEs must be informed by contemporary research in the learning sciences, by contemporary practice in education, and by the practical realities of institutions and funding.

Almost all immersive and non-immersive VLEs have some form of audio applied to them from either background music, playback audio from embedded videos, embodied autonomous agent(s), and/or avatar(s). Fassbender, Richards, Bilgin, Thompson, and Heiden (2012) wanted to study the effect from the connection between music and cognitive tasks in VLEs in spite of already knowing that music had been shown to affect learning. The research question was how does background music affect
human memory of facts that are conveyed in a non-interactive virtual environment? The foundation to their two experiments is a computer animated history lesson, called VirSchool. Along with the independent variable of music in experiment two being evaluated so was how different display systems (i.e. three monitor desktop display system and immersive semi-cylindrical three wall projector display system) influenced participants’ memory of historical facts. The convenience sample was 48 undergraduate students (28 female) recruited through various lectures at Macquarie University in Sydney, Australia. Four questionnaires concerning biographical data, memory of facts, participants’ preference of video narration parts, and feelings of immersion in the VLE collected the data. Based on conditions and variables the authors used a variety of statistical methods, such as descriptive statistics analysis, paired and independent $t$-test, and repeated measures ANOVA. The major finding concerning learning and which was unexpected by the authors based on previous research was that the non-immersive three monitor desktop display system stimulated significantly higher memory of facts from the VirSchool history lesson over the immersive display system.

The final article reviewed concerning the use of a projection based VR system is by Patera, Draper, and Naef (2008). They examined the impact of an immersive VLE (stereoscopic wall display VR system) on learning the English language, and more specifically on imaginative writing. A strike contrast to the majority of the research on immersive VLEs, which have focused on science related subjects. The main aim of the research was to see if interactive immersive VLE increases motivation and stimulates participant’s imagination in imaginative writing. The authors hypothesized that participant motivation would increase due to immersive VLE exposure. The convenience
sample was 15 participants from two primary schools in the West Dunbartonshire education authority in Scotland, Ireland. Participants were divided into three intervention groups (immersive IVE, non-immersive/non-digital, and traditional pedagogy from teacher) for comparison. Interviews with teachers, observations, and imaginative story creation collected the data. The authors analyzed the independent variables of motivation and creativity quantitatively by word count of the participants’ imaginative stories and qualitatively by video recordings, observations, and teachers’ comments. Additional evaluation of criteria, such as description of senses and emotions, storyline, fantasy, and sequence of events took place. An independent teacher performed analysis of the imaginative stories. None of the measures used showed significant benefits for motivation or creativity however, participants remained engaged (the immersive VLE group the most) throughout the experiment. There was also positive praise from the teachers on the effectiveness and value of the new technology.

*Head mounted display*. The following pieces of literature either primarily used a HMD or compared it against other display technologies in the research. The use of a HMD and an VLE for educational training is a focus of the current research. “Presence is the main attribute, the defining experience for VR” (Mikropoulos & Strouboulis, 2004, p. 582). If true then research needs to show which specific components of a VR system and how the user’s age influences presence. Mikropoulos and Strouboulis (2004) purpose was to investigate the sense of presence of children while navigating as an exocentric avatar in an immersive VLE using various input devices for interaction. The immersive VLE was representative of an ancient house in Kassiopi, Greece and the interactive actions within had historical and educational learning goals. No direct research questions or
hypotheses are given. The convenience sample was 29 elementary students (14 females) with an age of 12. An exit questionnaire containing 54 closed ended and six open ended questions collected the data. The questions were in one of six categories a) prior computer use, b) manipulations with input device, c) activities, d) VE, e) avatar, and f) HMD. Additional recordings concerned the time needed to complete each task within the VLE. A combination of descriptive statistical analysis (mean) and chi-square tests evaluated the data. A general summation of the major findings is “with educational VEs, the computer’s world becomes the user’s world, the user experiences presence within that world, the user is an integral part of the stimulus flow and constructs knowledge within the domain under study” (Mikropoulos & Strouboulis, 2004, p. 590).

In keeping with the focus on researching presence Mikropoulos (2006) aims at investigating if presence in an VLE contributes to positive learning outcomes and if the avatar’s point of view (egocentric or exocentric) in the VLE effects the level of presence. The experiment design was similar in fashion to Mikropoulos and Strouboulis (2004) study on the grounds that participants had to listen to oral instructions to navigate through and interact with the IVE to complete certain tasks, which had historical and educational learning goals. There were four conditions for the within-subject experiment a) wall projected/exocentric, b) wall projected/egocentric, c) HMD/exocentric, and d) HMD/egocentric. The sample had 60 participants (23 females) ranging in age from 11 to 13. A presence and learning outcome questionnaire developed by the authors along with observations and the software (e.g. log files) collected and recorded the data. A combination of descriptive statistical analysis (mean and standard deviation), $t$-test (distributions normal), and Wilcoxon Signed Ranks (distribution not normal) were used
to evaluate the data. Two major findings of importance were that the optimal combination for presence was the HMD and an egocentric point of view, and the specific contents of a VLE in combination with specific learning tasks affects presence and task performance.

Immersion and presence are just a few of the many unique affordances of immersive VLEs that can have a positive effect on learning processes and outcomes. Embodied agents that teach and learn, virtual co-learners, visualizations, synthesis of archived behaviors, and simulation of dangerous or expensive lessons are others (Bailenson, Yee, et al., 2008). In a series of four preliminary experiments, Bailenson, Yee, et al. (2008) began investigating the impact of pedagogy and learning when teacher and learner were both placed in an immersive VLE simultaneously. The following is the hypotheses for experiments one thru four respectively a) an teaching avatar could spread their gaze more uniformly to the class than a live instructor b) learning would increase when the learner is placed in the middle of a virtual classroom, c) learning would increase when the learner is placed closer to the instructor in a virtual classroom, and d) learning would increase when placed with a “model student” co-learner over the distracting virtual student condition. The sample for experiment one was 40 undergraduate students (20 female) split evenly amongst the four between-subject conditions. The second experiment had 32 Stanford University students (16 female) while experiment three had 44 (20 female) students participate. The fourth experiment equally split eighty-two undergraduate students in terms of gender and the three between-subject conditions. Besides real time recordings of the participants within the VLE in all four experiments, experiments two thru four also used multiple-choice exams. A combination of descriptive statistics and ANOVA analyzed the four experimental data sets. “In sum, the practical
implications of the current work are clear: Digital transformations through media can increase students’ learning in some contexts” (Bailenson, Yee, et al., 2008, p. 131).

Salzman et al. (1999) gives details on project ScienceSpace (also see C. Dede, Salzman, and Bowen Loftin (1996)), which consists of three immersive VLEs a) NewtonWorld (Newton’s three laws), b) MaxwellWorld (electrostatics), and c) PaulingWorld (quantum-mechanical bonding) that are utilized to identify, use, and evaluate features of immersive VLEs that assist conceptual learning. NewtonWorld has gone through three evaluation studies. The first focused on interaction and usability experience, and had a convenience sample size of nine high school students (five females). Researchers used a combination of observations, questionnaires (e.g. likes-dislikes, ease of use, etc.), and system recordings (e.g. task completion time, error frequency, etc.) for data collection. The second evaluation had a convenience sample of 107 physics educators and researchers who used and evaluated NewtonWorld through a survey regarding the interaction experience, learning experience, learning process, and expected learning outcomes. Thirty high school students (12 female) ranging in age 16 to 18 preformed the third evaluation. Participant’s group assignment was to one of three groups a) visual cues only, b) visual and auditory cues, and c) visual, auditory, and haptic cues. Observations, usability questionnaires, interviews, and pre- and post- exams were used to data collection. MaxwellWorld has been through two evaluations. The first had a convenience sample of 14 high school and four college students participate. The focus was on learning (process and outcomes) and the interaction and learning experience. Observations, usability questionnaires, interviews, and pre- and post- exams collected the data. In the second evaluation a commonly used 2D software named EM Field™ was
compared against MaxwellWorld by a convenience sample of 14 high school students for learning, learning experience, interaction experience, and retention. PaulingWorld had no formal evaluation. The iterative evaluations of ScienceSpace and its individual VLEs yielded many findings (minor and major) however the a major conclusion can be summarized as “the success or failure of VR learning environments in practice critically depends upon the web of relations among VR's features, the concepts to be learned, learner characteristics, the learning experience, the interaction experience, and more” (Salzman et al., 1999, p. 315)

**Edutainment / Serious Games**

The popularity and playing of video games (e.g. massively multiplayer online game, first-person shooter, etc.) is at an ever-growing rate (Rideout, Foehr, & Roberts, 2010, Williams, Yee, & Caplan, 2008, Yee, 2006). “However, these games are mainly created for entertainment and do not aim at educating the targeted users” (Virvou & Katsionis, 2008, p. 154). There has been progress made and research conducted concerning the development of games for both entertainment and education, which are often aimed at increasing students’ motivation and engagement while learning (Virvou & Katsionis, 2008). Pan and Chen (2008) discuss hybrid VR projects aimed at combining education and entertainment:

Virtual reality (VR) has been proposed as a technological breakthrough that holds the power to facilitate learning. The research and application of VR technology in education has enriched the form of teaching and learning in current educational strategy. Virtual learning environments not only provide rich teaching patterns and teaching contents, but also improve the learner’s ability to analyze problems
and explore new concepts. Integrated with immersive, interactive, and
imaginational advantages, it builds a sharable virtual learning space that can be
accessed by all kinds of learners who inhabit the virtual community. Edutainment
is the integration of education and entertainment. (p. 1)

Along the same lines of edutainment is the relatively new movement in interactive
3D, which parts of the industry have begun to label as serious games. “It is generally
accepted that they are games with “a purpose”—games that go beyond entertainment to
deliver engaging learning experiences across a wide range of sectors” (Stone, 2008, p. 1).
This emerging field has been proposed as a second chance for VR to succeed after the
1990s roller coaster ride of VR achievements and failures (Stone, 2008). Based on the
previous definitions, I could have also categorized the current research project under
edutainment and the VLEs used within as serious games.

Learning

The current research is concerned with learning simply as general declarative
knowledge acquisition. The training information is gathered and received by the trainee
through simple interactions with active (e.g. game play) and passive (e.g. audio listening,
video watching and image viewing) media. Ragan et al. (2012) defined learning as “a
complex mental activity involving perceiving new information from external stimuli,
relating the new information with previously learned information, and storing the new
information in memory” (p. 302). “All educational VEs share the challenge of how best
to present learners with the new information within the 3D space” (Ragan et al., 2012, p.
302). This is in line with one of the major educational/training VR research areas, which
is to find out which components, characteristics, and/or affordances of VR (e.g. stereoscopy, FOV, FOR, immersion, presence, etc.) are most influential to learning.

This area of VR research is increasing as the move away from primarily investigating VR system usability has decreased over the last decade. Winn et al. (1999) explored students’ learning when they built their own immersive VEs (i.e. constructivism). Mania and Chalmers (2001) explored how different levels of immersion effected the learning experience (i.e. memory). E. A. Suma et al. (2010) and Zanbaka, Lok, Babu, Ulinski, and Hodges (2005) both report experiments investigating how travel, the motor component of navigation effects information gathering and cognition in immersive VEs. Bailenson, Patel, et al. (2008) demonstrated that immersive VR can provide better learning of physical movements than a 2D video. Minogue, Jones, Broadwell, and Oppewall (2006) even studied the efficiency of haptic augmentation of a computer-mediated instructional program on middle school students learning about animal cell structure and functions.

Ragan et al. (2012) had the purpose of investigating how the use of space affects the performance of learning-based activities (e.g. cognitive processing) within a VE. The hypotheses for experiment one were if the user was provided with greater support for spatial memorization strategies, and clear landmarks associated to the memorization sequence steps then better performance for sequence memorization and factual learning would result. The convenience sample was 32 university students and staff members (16 female) ranging in age 18 to 57 with a median age of 20. There was equal participant assignment to the four conditions of the between-subject experiment by age and gender. Observations, system logs (accuracy of and time to complete tasks), spatial aptitude test
(e.g. Kit of Factors Referenced Cognitive Tests), and interviews (to discuss user strategies) were used for data collection. A combination of descriptive statistics (central tendency and variability), ANOVA, two-tailed Spearman correlation, and three-way loglinear analysis analyzed the data. “Thus, the results of experiment one show that spatial presentations can not only affect performance in cognitive tasks, but also the strategies used to complete the tasks” (Ragan et al., 2012, p. 308). The second experiment moved away from a simple memorization task and towards a higher level of cognitive processing (e.g. problem solving). Hypothesizing that using spatial locations within a VE could help offload organizational processing and memory. Sample was 24 (10 female) engineering students with an age range of 18-22. Questionnaire (background/demographics), performance evaluations (accuracy of and time to complete tasks), mental workload test (e.g. NASA TLX scale), and exit interviews were used for data collection. A combination of descriptive statistics (central tendency and variability), and ANOVA were used in data analysis. Results showed no improvement in performance or reduction in mental workload when using spatial layout aids within a VE during critical-thinking activities.

The majority of the VEs created and researched to date for educational purposes have been focused around the fields of natural science (e.g. chemistry, physics, biology, etc.) and formal science (e.g. mathematics, etc.). These academic disciplines lend themselves well to the affordance of VR being capable of displaying phenomenons that are invisible to the human eye. Most of the research has also involved participants enrolled in primary, secondary, and higher education, which neglects the working class. Another example of such is Trindade et al. (2002), who created the virtual environment
Virtual Water, which consisted of microscopic concepts of study (e.g. molecular dynamics and atomic orbitals). The purpose of the study was to investigate whether students with higher spatial reasoning and comprehension abilities benefit more from VR use. The two research questions were a) how do students who do not have very strong backgrounds in Physics and Chemistry, but have high spatial aptitudes, respond to VEs with and without stereoscopic visualization and b) does the conceptual understanding acquired with VR vary with spatial aptitude? The within-subject experiment consisted of a convenience sample of 20 university freshman students (eight female) from the Chemistry, Physics, and Engineering departments. The multiple-choice questionnaire Provas de Avaliação da Realização Cognitiva (PARC) measured the independent variable of spatial aptitude. Guided interviews and questionnaires measured the dependent variables of conceptual comprehension (the degree to which the student understands a concept corresponds to the scientific explanation) and motivation. Descriptive statistics (central tendency and variability) and Wilcoxon test analyzed the data. Three findings of importance are a) students who begin with higher spatial aptitudes have increased conceptual understanding when using VEs, b) a main strength of VR is its ability to visually display situations which otherwise cannot be seen, and c) VR has the ability to give substance to abstract concepts.

“Concepts whose content deals with processes call for more than traditional teaching methods” (Mikropoulos, Katsikis, Nikolou, & Tsakalis, 2003, p. 176). The aforementioned perception caused Mikropoulos et al. (2003) to create an VLE for biology teaching. “In order for a VE to become an item of educational software and support knowledge construction, it has to involve specific didactic goals, integrated
educational scenarios, metaphors with pedagogical meaning, and induce didactic and learning outcomes” (Mikropoulos et al., 2003, p. 178). The purpose of the study was to investigate whether the VLE could be an effective tool to support learning and teaching of plant cell biology and the process of photosynthesis, and explore in-service teacher’s attitudes toward VR. Research questions were a) in general, what is the attitude of in-service teachers toward VR and VLEs and b) what is the effect on learning outcomes when using the VLE for plant cell biology? The convenience sample was 37 in-service primary school teachers (13 female) from Greece. This is the only study found that used teachers as participants. Pre- and post- questionnaires with open and closed ended questions categorized into three types (demographics, attitudes, and plant cells and photosynthesis learning) collected the data. The only data analysis given used descriptive statistics. Two major summations of the findings in line with the two research questions are a) teacher’s attitudes towards VLEs were positive and “that VR-based educational software could support knowledge construction in a number of scientific domains, its strong features being interactivity and safety in the educational environment ” (Mikropoulos et al., 2003, p. 180) and b) “an attractive and motivating context is not enough for knowledge construction. It has to be closely related to the topic under study involving specific didactic goals and learning tasks” (Mikropoulos et al., 2003, p. 180).

Long-term Retention

There is a scarce amount of empirical research on the combination of VR use and long-term retention. Even with the characteristic of long-term retention (see definition) having high priority for article ordering only two peered reviewed empirical journal articles could be found (Jia, Bhatti, & Nahavandi, 2012, Kontogeorgiou, Bellou, &
Immediate recall of learning after VR use, specifically concerning VR for educational applications requires further research, but more emphasize needs to be placed on exploring long-term retention (Ragan et al., 2010, Trindade et al., 2002, Waller et al., 1998).

The principles and concepts needed to describe an atom according to Quantum Mechanics (QM) are difficult for students of all ages and education level to comprehend (Kontogeorgiou et al., 2008). Kontogeorgiou et al. (2008) created the VLE “The Quantum Atom” to help students better understand QM and to create accurate mental images (e.g. atomic models) consistent with scientific knowledge. The purpose was to explore student’s learning outcomes and sense of presence after VLE interactions. They also explored long-term retention (two months later) of cognitive content and sense of presence. Thirty-eight first year students of the Department of Primary Education at the University of Ioannina took part in the experiment. An entrance, exit, and retention questionnaire and structured interviews were the instruments used. The only data analysis given used descriptive statistics (central tendency). Learning outcomes were positive and the sense of presence was significantly greater when students used the stereoscopic glasses inside the VLE. There were two major findings concerning retention a) the mental images from which were created during interactions inside the VLE were still present two months later and b) participants still believed they had experienced a strong “sense of being there” (presence).

The complexity of VR is at such an elevated level that it makes evaluation of VE training efficiency and effectiveness with a single criterion (e.g. interaction, human factors, learning, retention, etc.) near impossible (Jia et al., 2012). Jia et al. (2012)
presented research on their Virtual Training Environment, and evaluated it through affective learning outcomes (users perceptions of self-efficiency and perceived VE efficiency), skill-based outcomes (development of technical or motor skills), and cognitive based outcomes (performance and knowledge acquired – immediate and long-term) for evaluating VE efficiency and effectiveness. There were six hypotheses a) performance task outcomes will be positively affected by self-efficacy, b) self-efficacy will positively affect perceived VE efficacy, c) task outcomes will be positively affected by perceived VR efficacy, d) performance memory tests will show a positive relation between performance outcomes and recognition/recall, e) memory and perceived VE efficacy will show no direct connection, and f) memory and self-efficacy will show no direct connection. The convenience sample was 76 volunteers (20 females) with a diverse background and a lower age limit of 18 and max of 45. Questionnaire and interview were used to measure affective outcomes, skill-based learning outcomes were measured by software generated log files (time to complete tasks, errors, user actions within VE, etc.), and cognitive learning outcomes were measured using a memory test and then redistributing it one to two months later to examine long-term retention. “Four statistical analysis methods i.e. Factor analysis, Cronbach’s alpha, Pearson’s correlation and Regression analysis were used, where appropriate, to validate user perception measures and to explore the hypothesized relationships among multiple measurement outcomes” (Jia et al., 2012, p. 1). The authors only received 18 retention exams, however they reported moderate to high performance of recognition and recall.
Traditional Education vs. Virtual Reality

Most of the evaluations of VR, specifically VE for educational application have been aimed at the factors that affect the interaction experience, such as immersion, presence, engagement, motivation, and usability; or human factors issues, such as cognitive workload, motion sickness, and after effects (Jia et al., 2012). There is a need for much more empirical research concerning traditional instruction and VR-based instruction. Wang (2012) even states “no researchers explored the relationship between VR and traditional instructions in the past” (p. 422). An extensive literature search provided just three peer reviewed empirical journal articles and one conference paper containing measures to evaluate VR-based and traditional education as the main purpose or one of the conditions. There is a great need for additional research in this area to support the notion that VR and VLEs can provide educational benefit. Mikropoulos et al. (2003) believes “a major disadvantage of conventional teaching tools is that they limit self-action. Students often remain passive receivers of information and have no direct interaction and feedback, as they acquire knowledge as the third person and not with direct experiences” (p. 176). It should also be noted that the current research is in agreement with statements by Bowman et al. (1999) on that VR should not replace but augment tradition education because it is unforeseeable that a VLE could fully replace the complexity and the proven established benefits of traditional pedagogy. “Therefore, the VE is better suited to introduce material, create associations between abstract and spatial information, and to equip students for further learning” (Bowman et al., 1999, p. 325).
Bowman et al. (1999) did not study the educational benefits of a VLE by completely replacing the classroom teacher/instructor. Instead, they used the VLE as a complementary informational-rich educational tool. Thus, the research consisted of a group comparison study between traditional classroom lecturing and teaching augmented with the use of an informational-rich immersive VLE, called Virtual Zoo Exhibit. It teaches college students about the design principles used in constructing an animal habitat within a zoo, and the design of zoo exhibits was already part of the participants routine class lectures. The two hypotheses were a) “students who augment the normal class presentations by using the virtual zoo exhibit will have greater understanding and increased retention of the material, and thus will perform better in an evaluation and b) students who use the virtual zoo exhibit will be better equipped to learn when the same material is presented in class and will be able to form more mental associations, and thus will perform better in an evaluation” (Bowman et al., 1999, p. 325). The information, habitat, and control groups had eight (nine initial), three (six initial), and five (nine initial) participants respectively. Imperfect class attendance reduced the sample size. Participants had to fill out a background questionnaire and then five days after the lecture and VLE use an unannounced test with 26 questions was distributed. Test performance was analyzed with descriptive statistics (central tendency) and peripheral data, such as the number information types participants watched, read, or listened to inside the VLE and total time spent using the VLE was also recorded and analyzed. The major finding is “an educational information-rich virtual environment, when combined with normal classroom teaching, can produce increases in learning and a richer framework within which to associate spatial and abstract information” (Bowman et al., 1999, p. 329).
Crosier et al. (2000) purpose was to compare a non-immersive desktop VR application for teaching radioactivity in secondary school to traditional methods. This empirical study was also one of the very few completed in the field. No direct research questions or hypotheses are given. The convenience sample for the within-group quasi-experiment was 51 students (24 female) from schools in Nottinghamshire, United Kingdom. Instruments and materials used were the Virtual Radioactivity Laboratory, observations, questionnaire concerning computer and post-use attitude, computer attitude scale, topic test, and VR/VE instruction worksheet. The authors used descriptive statistics and variability statistics (Mann Whitney U Test, ANOVA, and post hoc \( t \)-test) to analyze the data. The major finding was that early consideration in the education design process needs to be given to how specifically VR will be used, and generally it is beneficial if some instruction takes place before VR use. “On examination of the quantitative results, it may be observed that no obvious benefits were found for the use of VR over traditional teaching methods (TTM) both in terms of test scores and attitude ratings” (Crosier et al., 2000, p. 340). However, the factors contributing to the null results may be the large ceiling for TTM scores, participant dropout, the desktop VR system was non-immersive, and participants of both groups felt that the VLE did not have adequate content.

Wang (2012) believed that past research had used VR as a learning facilitator, but failed to explore the connection between VR and education. Therefore, the purpose was to investigate the instructional affect VR has on enhancing learning in order to justify the benefits for instructors and VR designers. The two research questions were a) “the kind of students that can be facilitated through the help of 3D VLE, and b) the relationship between a conventional test (i.e., paper and pencil test) and the 3D VLE used in the
study” Wang (2012, p. 415). The convenience sample was 36 undergraduate students (21 female). Data collection consisted of a combination of a pre-test, questionnaire (demographics, computer-related skills, attitudes toward VR, participants position towards the questions, and open-ended questions for thoughts, attitudes, and comments), and post-test. A combination of descriptive statistical analysis (central tendency) and chi-square tests evaluated the data. Two major findings were given a) the use of a VLE moved the students from a passive learner to an active learner while enhancing their interest to learn and b) participants benefiting the most from VLE use were those that are not adapted to traditional learning. “Learning depends more than the transmission of knowledge; it also requires the ability of an educator to engage students to be immersed in a meaningful activity so that they can internalize the knowledge received” (Wang, 2012, p. 412).

The final detailed review by Brelsford (1993) is a very early example of using VR in an educational context, specifically physics education. This piece of literature is not from a peer-reviewed journal but rather conference proceedings. The author also clearly states that the two independent variables are of very different types and introduce many confounding variables. However, Brelsford (1993) states that it may just be the nature of the beast when trying to directly compare an instructional method, such as traditional lecture-based to VR-based multimedia instruction. The purpose of the study was to provide a useful comparative evaluation of VR-based and teacher-based/lecture-oriented instruction (i.e. control group). The measured dependent variable was long-term retention, which could have allowed this article to be categorized under the long-term retention section. Brelsford (1993) states the research question as, “are classroom
experiences, in such extraordinarily adaptive and user-sensitive contexts as virtual reality, superior to more traditional class-room education experiences” (p. 1286)? The sample was four groups (Junior high/VR, Junior high/control, University/VR, and University/control) of 14 students each. Each group had a different split of females to males and mean age. Means to collect data began with a pretest, which contained 50 multiple-choice questions. Following both type of instruction and a four-week interval the participants took an unannounced and unexpected long-term retention test consisting of 50 multiple choice physics knowledge and computation items. A combination of descriptive statistical analysis (central tendency) and ANOVA was used to evaluate the data. “Findings generally indicated that virtual reality-based learning is superior to lecture-based control conditions” (Brelsford, 1993, p. 1286).

Corrosion

In 2002, the U.S. Federal Highway Administration released a two year study, which estimated the United States direct cost of metallic corrosion at $276 billion, approximately 3.1% of the nation’s gross domestic product (Koch, Brongers, Thompson, Virmani, & Payer, 2002). The annual cost of corrosion for the DoD is estimated at over $20 billion per year, roughly 23% of the DoD maintenance budget (Herzberg, 2009). $1.6 of that $20+ billion is Army aviation alone, representing roughly 20% of the total AMCOM maintenance costs (Carr, 2009). With costs so high and the inability to ever fully stop corrosion, which is “the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment” (National Association of Corrosion Engineers, 2011, pp. 1-1), caused the U.S. Congress to act. In December 2002, Congress enacted Public Law 107-314, §1067 (codified at 10 U.S.C. § 2228), titled Prevention and
Mitigation of Corrosion of Military Equipment and Infrastructure. This required the Secretary of Defense to accomplish actions to prevent and mitigate corrosion of the Department’s military equipment and infrastructure ("Bob Stump National Defense Authorization Act for Fiscal Year 2003," 2002). Along with Congress requesting that the General Accounting Office review military activities related to the prevention and mitigation of corrosion (United States General Accounting Office, 2003), the law required that the DoD designate a responsible official or organization to oversee corrosion prevention and mitigation. This lead to the formation of the Corrosion Policy and Oversight Office (Corrosion Policy and Oversight Office, 2011). The Corrosion Policy and Oversight Office (2011) states their mission and overall objective as:

The DoD mission related to corrosion prevention and mitigation is to implement a DoD wide program to standardize and substantially improve strategies, objectives and processes to prevent, detect and treat corrosion and its effects on military equipment and infrastructure. The ultimate objective is to reduce the negative operational effects and associated total ownership cost of military equipment and infrastructure. (p. 6)


The U.S. Army AMCOM CPO sponsored and/or supported this project and research study. Therefore, from this point forward, even though corrosion affects everyone only the Army will be the focus. To date, The Department of the Army’s current CPC Executive is Mr. Wimpy D. Pybus (appointed in 2009). Mr. Steve Carr is the program manager of the Army AMCOM Corrosion Program, which was formed in accordance with Army Regulation (AR) 750-59 (Headquarters Department of the Army, 2005). Mr. Carr and his team are a direct result of the U.S. Army, Army Reserve, and Army National Guard’s aviation and missile system’s corrosion issues and the above legislation that have been passed by government to fight it.

Training / Education

Initiated by the escalating corrosion costs and the Army placing top priority during war and peace time on training (Headquarters Department of the Army, 2002), a search for a solution to the corrosion problem began in early 2000s. If the Army identifies a gap(s) in their warfighting capabilities, they normally make changes in one or more material and non-material entities, namely: doctrine, organization, training, material, leadership, education, personnel, facilities, and policy (Pybus, 2013). The Corrosion
Policy and Oversight Office since has developed and made freely available a variety of corrosion training and education courses, programs, plans, strategies, and/or doctrine since its formation. Recently launching an e-portal, called CorrConnect (http://www.corrconnect.org). Here a variety of free corrosion courses, tutorials, and games are accessible to anyone. According to Daniel J. Dunmire, director of the DoD Corrosion Policy and Oversight Office, “the corrosion courses housed on CorrConnect incorporate video, animation, closed captioning, mini-games, lectures, quizzes, and exams in order to teach, engage, and entertain users while they are learning about the science of corrosion and the practice of mitigating it” (Greenwood, 2013, p. 1). The websites of CorrConnect and CorrDefense (http://www.corrdefense.org) can be looked as the DoD’s and in some aspect the industry’s central hub for CPC training, education, and information. Dunmire (2012) reports that CorrDefense had over 150,000 total visits in over three years with the majority of the visitors being non-military. It is easy to see that the strides made by the Corrosion Policy and Oversight Office have been immense for CPC education and training. Their interactive and engaging training resources and tools, which contain passive and active media, will continue to help in the fight against corrosion. However, none of the current tools or resources utilizes immersive VR technology (i.e. HMD). It should also be noted that the Army does not allow virtual simulations to replace all live training, they may only complement or augment (Headquarters Department of the Army, 2002).

The AMCOM CPO, which is the result of combining three separate entities (i.e. the AMCOM CPO, the Corrosion Prevention and Control Center of Excellence, and the Non-destructive Testing Center of Excellence), offers very different forms of assistance,
education, and training. The *Cleaning and Corrosion Control* manual (TM 1-1500-344-23), which was established jointly by the Navy, Air Force and Army states, “all activities responsible for aircraft maintenance shall establish corrosion control programs as required by the parent service organization” (Commander of Naval Air Systems Command, 2005, pp. 2-2). For the Army it must be structured as required by AR 750-59, which the AMCOM CPO has the ability to devise and help implement. The other forms of corrosion-based assistance provided are program manager assistance and field assistance (e.g. technical support). TM 1-1500-344-23 also states, “personnel performing maintenance on aircraft shall be trained in basic corrosion control skills as established by the parent service organization” (Commander of Naval Air Systems Command, 2005, pp. 2-3). The AMCOM CPO helps satisfy this requirement by in-field CPC training or the in-house corrosion monitors course. This research study used both types for research sites and participant recruiting (see Participants section).

The accessibility of the above examples are generally targeted and/or limited to the military. Civilian opportunities for post-graduate education and professional development concerning corrosion are available. One example that the Corrosion Policy and Oversight Office helped setup is the corrosion specific Defense Acquisition University (http://www.dau.mil/default.aspx) course titled, *CLM 038 - Corrosion Prevention and Control Overview*, which has over 2,700 graduates (Dunmire, 2012). NACE International (formally known as The National Association of Corrosion Engineers), which is the world’s leading professional organization on corrosion (http://nace.org) also provides a vast array of educational offerings from online training (e.g. webinars, continuous learning, etc.) to short course certification programs (e.g.
corrosion technician, cathodic protection, etc.). According to Cliff Johnson, NACE Public Affairs director (as cited in Larsen 2008), "training is the first step in corrosion prevention and control." "Without training, the best corrosion prevention tools in the world will not be effective." Today, NACE and the DoD continue to work together to provide invaluable support through education, training, and the dissemination of cutting-edge knowledge and information (Larsen, 2008). NACE is also an integral part in the organizing of numerous international conferences for corrosion professionals, researchers, and industries (e.g. Corrosion every year and the Department of Defense Corrosion Conference every two years). Traditionally, the above examples or an educational route leading to an Master of Science or Doctors of Philosophy in corrosion science are the avenues for post-graduate corrosion training (Scully & Harris, 2012).

In 2009, the National Research Council (NRC) released a report, titled Assessment of Corrosion Education that accessed the current state of corrosion engineering education in the U.S. “The NRC study found that undergraduate corrosion education was non-existent in many engineering schools” (Scully & Harris, 2012, p. 68). Since then The University of Akron with the help of the Corrosion Policy and Oversight Office created a degree program for a Bachelor of Science in Corrosion Engineering (http://www.uakron.edu/uakroncorrosion/), which is the first of its kind in the United States. Finally, Scully and Harris (2012) review of the NRC report concludes:

The current level of effectiveness of corrosion engineering curricula in the U.S. is not sufficient to address the nation’s need to improve safety, reliability, and reduce costs due to corrosion. To remedy this situation, corrosion engineering education, training, and research must be addressed at several levels: (1) short-
term initiatives by universities, government, and industry and (2) long-term initiatives jointly taken by the federal government and the U.S. corrosion research community. (p. 70)

**Learning Tools and Techniques**

The majority of the training and education opportunities discussed above rely heavily on traditional instruction. Most often you will find an instructor giving a lecture accompanied by a presentation (e.g. PowerPoint or hands-on), also commonly referred to as *death by slide presentation*. The Army has followed this teaching style for decades. One of the issues with it is that “passive, lecture-based instruction does not engage learners or capitalize on prior experience” (Headquarters Department of the Army, 2011, p. 7). The enormous advances in technology now provide new learning opportunities. TRADOC Pam 525-8-2, *The U.S. Army Learning Concept for 2015*, is a strategic document that discusses some of these opportunities and lays the groundwork for where the Army’s learning model needs to be at in the coming years (Headquarters Department of the Army, 2011). According to the Headquarters Department of the Army (2011), the three initial implantation steps are:

1. “Convert most classroom experiences into collaborative problem-solving events led by facilitators (vice instructors) who engage learners to think and understand the relevance and context of what they learn.” (p. 9).
2. “Tailor learning to the individual learner’s experience and competence level based on the results of a pre-test and/or assessment.” (p. 9)
3. “Dramatically reduce or eliminate instructor-led slide presentation lectures and begin using a blended learning approach that incorporates virtual and constructive simulations, gaming technology, or other technology-delivered instruction.” (p. 9)

Computers and the Internet are widely available but some of the newer or developing technology-enabled learning/training tools and techniques are: mobile learning, open content, e-readers, cloud computing, gesture-based interfaces, gamification, e-learning, adaptive learning, blended learning, intelligent tutoring, virtual and augmented reality, increased automation and artificial intelligence, and massively multiplayer online games. These tools and techniques are a long ways away from possibly the first implementation of an unconventional training and education tool used in the Army, the M16A1 Rifle Operation and Preventative Maintenance booklet, which was issued in comic book form during WWII (Headquarters Department of the Army, 1969).

Nevertheless, it is important to keep in mind that technology will continue to play an important role in the daily lives of everyone; however, it cannot be looked at as a cure-all or the centerpiece in the global transformation of learning. It must be treated as an enabler, which allows learning content to be more operationally relevant, engaging, interactive, tailored, and accessible (Headquarters Department of the Army, 2011). The majority of soldiers are now considered digital age learners, who use digital technology and digital media heavily for entertainment and communication. If the Army wishes to implement a new learning model than they must close the growing gap between the use of digital media in and out of Army institutions (Headquarters Department of the Army, 2011).
METHODOLOGY

Permissions

This research study required prior approval and/or permissions from various individuals, organizations, and agencies (i.e. stakeholders). The first was from Intuitive Research and Technology Corporation. *INTUITIVE* is the an aerospace engineering and simulation company that has a strong reputation on Redstone Arsenal in Huntsville, Alabama for providing excellent technical services for the DoD. It was *INTUITIVE* who initiated this project, which overtime matured into this doctoral research study. Not only did they provide senior management support and guidance, as needed throughout the process, but also the VR system and various materials. The second and most needed was from the AMCOM CPO, which is located on Redstone Arsenal in Huntsville, Alabama. The AMCOM CPO was the intended customer/user of the VR products (i.e. VR system and VLEs) developed during this research study. They provided VLE resources (e.g. corrosion videos, photos, etc.), guidance, and support (e.g. research sites, participant recruiting, etc.) as needed throughout the project/research. Other required approvals and/or permissions concerning the DoD and the U.S. Army were unit commander support as needed and a U.S. Army Human Research Protections Office (AHRPO) component level administrative review. The final approvals and/or permissions came from the graduate study committee, UAB’s Mechanical Engineering Department and Institutional Review Board (see APPENDIX A), and informed consent from all research study participants. From the time I initially conceptualized the product (i.e. VR system) and
research study to documenting the results, I effectively managed all the stakeholders involved.

**Design**

The research study took part in two phases. Phase one consisted of a focus group (two parts) to provide face and content validity for the questionnaires, interview script, and exams. Phase two consisted of a formal research study, which was a group comparison experiment. Both phases of the research study were classified as minimal risk and I designed the experiment with limited input from the stakeholders.

**Focus Group**

There were two parts to the focus group. Part one was to provide face and content validity for the pre-exam, entrance and exit questionnaires, and interview script. Participants completed (i.e. filled out) and discussed the instruments in a group discussion format, which I proctored. Investigation of the pre-exam scoring insured that there was adequate room for scoring improvement (i.e. learning) after participants received either type of training in the formal research study (see Formal Research Study section).

Part two of the focus group was to provide face and content validity for the pre-, post-, and long-term retention exams. I accomplished this by having corrosion subject matter experts and CPC instructors from the AMCOM CPO review the exams. They investigated the exam questions for accuracy, level of difficulty, and appropriateness for the targeted research study participants. Part two took place before part one.
**Formal Research Study**

The experimental formal research study was a mixed ANOVA design (also known as split-plot design) and is where the validated instruments from the focus group were utilized. The formal research study compared 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 and long-term retention of basic CPC knowledge in the participants after taking an AMCOM CPO’s CPC training course. The categorical between-participant independent variable was the type of multimedia instruction (two levels), which was either instructor-led lecture-based (i.e. PowerPoint presentation) or VR-based multimedia instruction (i.e. immersive VLEs containing an animated pedagogical agent). The two independent groups were characterized as control and investigational. The investigational group consisted of the randomly assigned participants who received the VR-based multimedia instruction. 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-, post-, and long-term retention exams). The continuous dependent variables of learning outcomes (position one) and long-term retention outcomes (position two) were measured for each group across each condition of the repeated measure. The scoring differentials (i.e. gain scores) between exams were also explored. Finally, the study evaluated the VR system’s ease of use, ease of learning, user comfort, likability, acceptability, and satisfaction. Examining the subjective entrance and exit questionnaires and the interviews provided the usability evaluation.
Participants

The convenience samples in part one of the focus group and the formal research study were U.S. Army soldiers who had enrolled in a routine AMCOM Corrosion Program CPC training course. The participants in part two of the focus group were corrosion subject matter experts and CPC instructors from the AMCOM CPO. The control group consisted of participants who received the routine classroom instructor-led training (i.e. lecture-based multimedia instruction). The investigational group consisted of randomly assigned participants who received the immersive VLE training (i.e. VR-based multimedia instruction), which was subdivided into three training modules a) usage module, b) training module one, and c) training module two (see Immersive VLEs and Procedure and Setting sections for more details).

Materials

Entrance and Exit Questionnaire

The entrance questionnaire obtained participants general background information and information concerning inclusion and exclusion criteria. It also gathered information on computer, smart phone, video game, and VR familiarity and usage. The question types were closed-ended (e.g. yes/no/unsure and scaled), open-ended (e.g. sentence completion), and contingency. The scaling method used was Likert scaling (Vagias, 2006). Analysis and scoring of each entity and response was separate (i.e. not summed).

Exclusion criteria:

- Under 18 years of age (focus group and formal research study)
- A always response to motion sickness (only investigational group)
- A wearing glasses response (only investigational group)
• A *yes* response to any of the first 15 health concerns (only investigational group)

• A *no* response concerning the participant’s belief that he or she could safely perform the tasks required during the VR-based multimedia instruction (only investigational group)

The exit questionnaire 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.) concerned with the received VR-based multimedia instruction. The questions were closed-ended (e.g. yes/no/unsure, scaled, and multiple choice). The scaling method used was Likert scaling (Vagias, 2006). Analysis and scoring of each entity and response was separate (i.e. not summed).

**Exit Interview**

Short interviews after the receiving the VR-based multimedia instruction helped further understand the experiences of the participants in the investigational group. This form of data collection was different from the questionnaires in that it was more exploratory and seeking of central themes from the participant’s responses. The interview contained six open-ended questions.

**Pre-, Post-, and Long-term Retention Exams**

The objective of the exams was to provide a means for assessing learning and long-term retention in terms of general declarative knowledge. 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. The pre- and post- exams were paper based (created with Microsoft® Word®) and the long-term retention exam was web based and password protected. The long-term retention exam was created using Qualtrics® (http://www.qualtrics.com/) and contained the same questions and ordering as the post-exam. I did not allow the participants to see the correct answers after taking any of the exams, and they could only take each exam once. I implemented these measures along with the restriction of not being allowed to use any reference material (e.g. textbooks, internet, notes, etc.) or talking while taking the exams to help prevent cheating and answer sharing. This also insured that I did not violate the assumption of independence.

I created five different exam topics, which permitted the methodically grouping of the exam questions. All the questions were classified as being in the knowledge category from Bloom’s Taxonomy of educational objectives (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), which is a popular scheme for classifying educational goals and objectives (Krathwohl, 2002). The number of questions under each topic is not equal because the training delivered to all participants (control and investigational group) was divided unequally in the amount of information and the actual training time across the five exam topics (see Table 1).
Table 1

*Number of exam questions by exam topic and cognitive domain*

<table>
<thead>
<tr>
<th>Categories</th>
<th>Importance of CPC</th>
<th>Corrosion Basics</th>
<th>Corrosion Influences</th>
<th>Corrosion Types</th>
<th>Corrosion Prevention (basics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Comprehension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Synthesis</td>
<td></td>
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<tr>
<td>Evaluation</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(9%)</td>
<td>(18%)</td>
<td>(18%)</td>
<td>(32%)</td>
<td>(23%)</td>
</tr>
</tbody>
</table>

**Notes.** The categories listed are the six major categories in Bloom’s cognitive domain. Bloom ordered the categories from simple to complex and from concrete to abstract (Krathwohl, 2002).

I aligned both forms of the training (i.e. lecture-based and VR-based multimedia instruction) and exam questions with the five learning objectives that I created (also approved by the AMCOM CPO).

The exam topics covered by the training material presented in training module one during the VR-based multimedia instruction were the importance of CPC, corrosion basics, and corrosion influences. Training module one also provided the participants with the training (i.e. information) needed for the following learning objectives:

- **LO1:** Demonstrate their knowledge of why CPC is important by *identifying* and *selecting* the outcomes of past lack thereof.
- **LO2:** Demonstrate their knowledge of corrosion by *identifying* and *selecting* characteristics of the definition.
• LO3: Demonstrate their knowledge of the mechanics of corrosion by identifying and selecting the individual components of corrosion and possible influences.

The exam topic covered by the training material presented in training module two of the VR-based multimedia instruction was corrosion types. Training module two also provided the participants with the training (i.e. information) needed for the following learning objectives:

• LO4: Demonstrate their knowledge of identifying different types of corrosion by selecting each type.

• LO5: Demonstrate their knowledge of different types of corrosion by identifying and selecting characteristics of each type.

The exam topic covered by the training material presented in the usage module of the VR-based multimedia instruction was basic corrosion prevention. The usage module also provided the participants with the training (i.e. information) needed for the following learning objective:

• LO6: Demonstrate their knowledge of basic CPC techniques, theories, and principles.

The process of ensuring that both groups received the necessary instruction (i.e. training material), which would allow both group’s participants to be able to answer the exam questions and meet the learning objectives, was very important. I made sure that the information the investigational group received through the training was in parallel with the control group by receiving and reviewing the PowerPoint presentations from the
instructors at the AMCOM CPO and attending numerous routine CPC training courses in advance of creating the exams and scripting the VLEs.

The following tables and APPENDIX B provide additional details on the exams. Specifically, the tables provide the correlation between exam topics and the individual questions and the correlation between VLE activity and the individual questions.

Table 2

*Exam question breakdown by topic*

<table>
<thead>
<tr>
<th>Exam</th>
<th>Importance of CPC</th>
<th>Corrosion Basics</th>
<th>Corrosion Influences</th>
<th>Corrosion Types</th>
<th>Corrosion Prevention (basics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-exam Questions</td>
<td>1, 12</td>
<td>4, 6, 7, 15</td>
<td>3, 8, 9, 11</td>
<td>5, 17-22</td>
<td>2, 10, 13, 14, 16</td>
</tr>
<tr>
<td>Post-exam Questions</td>
<td>4, 16</td>
<td>1, 6, 9, 14</td>
<td>2, 7, 10, 11</td>
<td>5, 17-22</td>
<td>3, 8, 12, 13, 15</td>
</tr>
</tbody>
</table>

*Notes.* The long-term retention exam follows the same breakdown as the post-exam
Table 3

*Pre-exam question breakdown by VLE activity and topic*

<table>
<thead>
<tr>
<th>Module</th>
<th>VLE Activity</th>
<th>Importance of CPC</th>
<th>Corrosion Basics</th>
<th>Corrosion Influences</th>
<th>Corrosion Types</th>
<th>Corrosion Prevention (basics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2, 16</td>
</tr>
<tr>
<td></td>
<td>Audio</td>
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<td></td>
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<tr>
<td></td>
<td>listening</td>
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<tr>
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<td>Video</td>
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<td></td>
<td>watching</td>
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<tr>
<td></td>
<td>Action</td>
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<tr>
<td></td>
<td>Shooter</td>
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</tr>
<tr>
<td></td>
<td>Jigsaw puzzle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10, 13, 14</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One:</td>
<td>Audio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1, 12</td>
</tr>
<tr>
<td></td>
<td>listening</td>
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<td>Video</td>
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<td></td>
<td>watching</td>
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<td></td>
<td>Action</td>
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<tr>
<td></td>
<td>shooter</td>
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<tr>
<td></td>
<td></td>
<td>1, 12</td>
<td>4, 6, 7, 15</td>
<td>3, 8, 9, 11</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Two:</td>
<td>Audio</td>
<td></td>
<td></td>
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<td>5</td>
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<tr>
<td></td>
<td>listening</td>
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<td></td>
<td>Jigsaw puzzle</td>
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<td></td>
<td></td>
<td></td>
<td>17-22</td>
</tr>
</tbody>
</table>

*Notes.* See Training Module One section for details on each VLE activity. Answers to various questions (italics) were covered twice (multiple activities).
Table 4

Post-exam question breakdown by VLE activity and topic

<table>
<thead>
<tr>
<th>Module Usage:</th>
<th>VLE Activity</th>
<th>Exam Topics</th>
<th>Exam Topics</th>
<th>Exam Topics</th>
<th>Exam Topics</th>
<th>Exam Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio listening</td>
<td>Importance of CPC</td>
<td>Video watching</td>
<td>Action Shooter</td>
<td>Jigsaw puzzle</td>
<td>Audio listening</td>
<td>Video watching</td>
</tr>
<tr>
<td>Video watching</td>
<td>Corrosion Basics</td>
<td>Action Shooter</td>
<td>Jigsaw puzzle</td>
<td>Audio listening</td>
<td>Video watching</td>
<td>Action Shooter</td>
</tr>
<tr>
<td>Action Shooter</td>
<td>Corrosion Influences</td>
<td>Corrosion Types</td>
<td>Corrosion Types</td>
<td>Corrosion Types</td>
<td>Corrosion Types</td>
<td>Corrosion Types</td>
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<tr>
<td>Jigsaw puzzle</td>
<td>Corrosion Prevention (basics)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One:</td>
<td>Audio listening</td>
<td>4*, 16</td>
<td>1*, 6, 9, 14</td>
<td>2, 7*, 10, 11</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Audio listening</td>
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<tr>
<td>Video watching</td>
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<tr>
<td>Action shooter</td>
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<tr>
<td>Two:</td>
<td>Audio listening</td>
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<tr>
<td>Audio listening</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Jigsaw puzzle</td>
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</tbody>
</table>

Notes. See Training Module Two section for details on each VLE activity. Answers to various questions (italics) were covered twice (multiple activities). *new questions

VR System

The AMCOM CPO had three original requirements for the VR system a) low-cost, b) portable, and c) scalable. Those requirements forced the product selection process to take place early on in the project. First choice was always commercial off-the-shelf (COTS) products. After I researched commercially available VR hardware and software and through a thorough selection process, I choose the Wirks™ (Schluer, 2012) VR bundle by WorldViz® (http://www.worldviz.com/). It provided an affordable solution for
stereoscopic 3D viewing and user tracking in a COTS package that was easy to learn, appropriate for PhD level research, and met the requirements listed above. The Wirks system was the foundation to the VR system that I ultimately created and utilized during the formal research study. The task of integrating all these various hardware and software pieces was a challenge.

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)

**Hardware**

The Sony HMZ-T1™ was the HMD that provided the participants with immersive stereoscopic 3D viewing while performing the interactive simulations (i.e. training modules). The HMD had duel independent organic light-emitting diode (OLED)
screens, each one with a 720x1280 resolution, and each capable of 60 Hz. Vizard (see Software section) ran the interactive simulations using the standard method of top-and-bottom (TaB) video streams. The software would process each video stream and down sample each to frames of half the vertical resolution (720/2 = 320 horizontal lines). These frames were then combined TaB to produce the combined output stream of 720x1280/60p. Finally the external video control unit (i.e. processor unit), which was connected to the laptop by a high definition multimedia interface (HDMI) cable would take the stream and separate the top and bottom halves, unpacking each frame and stretching each back to fill the 720 horizontal lines in their respective eyepiece (Sarchet & Kim, 2012). The HMD had a horizontal FOV of 45 degrees, diagonal FOV of 51.6 degrees, 5.1-surround sound capability, interpupillary distance (IPD) adjustment, and weighed approximately one pound.

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). The Kinect incorporates several advanced pieces of hardware and capabilities (e.g. depth sensor, color camera, four-microphone array, facial recognition, and voice recognition) into a low-cost and widely available product, which has extended far beyond just the gaming industry (Zhang, 2012). The OS3D determined in real-time where the user was looking based on three degrees of orientation (i.e. yaw, pitch, and roll) of the user’s head. Vizard (see Software section) processed the information, in combination with the Kinect’s head position data in order to render the interactive simulation being displayed on the HMD, while ensuring that the user’s
viewing perspective was being updated correctly in real time (Sarchet & Kim, 2012). Interactions (e.g. travel, selection, manipulation, and system control) within the VLE were performed through tracked body movements by the Kinect and participant input using a Bluetooth® Zeemote® JS1 controller (http://www.zeemote.com/).

A Dell® M4600 laptop with a NVIDIA® Quadro® 2000M graphics card, Intel® Core i7-2620M duel core processor, 8 GB RAM, and Windows 7 (64-bit) operating system ran the VR system. Additional components were various cables (e.g. Kinect extension), cords (e.g. surge protector and extension cord), disinfectant wipes, Kinect mounts (e.g. tripod and monitor mount), a backpack, and a yoga mat (i.e. tactile feedback), which also represents standing on the platform in the VLE (see Immersive VLEs section).

**Software**

The most important piece of software for this research study was Vizard™ (http://www.worldviz.com/products/Vizard) by WorldViz, which was included in the Wirks VR bundle. It enables Python® (http://www.python.org/) 2.4 scripting language, which provided a novice programmer a user-friendly scripting environment. The VR toolkit created and controlled the VLE content and integrated all the various hardware pieces. Vizard supports numerous motion trackers, displays, and input devices. It also supports 3D models, sound, and video importing, advanced avatar features, and the ability to publish as executable. The OpenGL® (http://www.opengl.org/) based architecture of Vizard provided the fast and efficient rendering. Bridging the Kinect data and Vizard was FAAST™ (http://projects.ict.usc.edu/mxr/faast/), which was the middleware that enabled the full body control and tracking of the interactive simulations.
The open-source software also has a configurable input emulator that can detect human actions and bind them to virtual mouse and keyboard commands (Lange, Rizzo, Chang, Suma, & Bolas, 2011, Evan A. Suma, Lange, Rizzo, Krum, & Bolas, 2011). FAAST streams the user’s skeleton data, which consists of 24 joint transformations (including position and rotation) to Vizard. The Zeemote JS1 controller came with Zeekey® for Windows ("Zeekey® for Windows," 2010), which was a free downloadable software that emulates a standard three button computer mouse. This allowed for the custom key mappings that I needed.

I also needed additional software for creating and/or editing portions of the training material (e.g. videos, images, recordings, audio clips, etc.) and resources (e.g. VR world/scene, avatar, CAD models, embedded autonomous agent, etc.). I created and/or edited the educational training material with Windows Live Movie Maker, Audacity® (http://audacity.sourceforge.net/), and basic imagine resizing software. The creation and/or editing of the VLE resources was done with Autodesk® 3ds Max™ (http://usa.autodesk.com/3ds-max/), SolidWorks® (http://www.solidworks.com/), and Vizard.

**Immersive VLEs**

The participants of the investigation group performed interactions (e.g. travel, selection, manipulation, system control, etc.) within three different immersive VLEs (See Figure 2). I story boarded each VLE and worked with the AMCOM CPO prior to actual programming to ensure I met their expectations. Top priority during conceptual design was to increase the possibility of entertainment, engagement, and/or provoking emotion from the participants while fostering increased learning and long-term retention. Vizard
(see Software section) was the software that programmed and controlled the modules. All three modules also used the same base VR scene (i.e. world), which was called the pit.

The pit’s built in animations included the rising and lowering of the platform and floor. It also contained a model of a large movie screen, which I utilized to display images, videos, text, etc. (see Figure 3).

**Figure 2.** Immersive VLE sequence. *Note.* Exam topic(s), learning objective(s), and game type(s) given (i.e. bullets) for each training module.

**Figure 3.** Egocentric view of the VLE. *Note.* The platform is raised, pit lowered, and the movie screen is blank (i.e. black).
A very important resource needed for all the modules was the fully animated avatar, which represented the animated pedagogical agent. To save time and costs I decided to purchase a COTS agent from Rocketbox Studios (http://www.rocketbox.de/), which WorldViz then optimized for Vizard (see Figure 4). WorldViz programmed the agent to walk, talk, look at, etc. at specific times and before or after certain user actions during each training module. I also had them link the agent’s viewing direction to the user’s main viewpoint to encourage normal human communication behaviors. When the agent spoke, an audio file would move the lips and jaw according to the file’s amplitude. There were six audio files for training module one, eight for training module two, and eight for the usage module. I developed the script for each and completed the recordings myself (i.e. used my voice) with a personal pop screen and Samson Go Mic®.

The figure below shows a red crosshair (i.e. mouse pointer). The crosshair was linked to the Bluetooth Zeemote JS1 controller, which the user held in their hand (left or right). When queued the crosshair would appear and move as the user moved their hand because of the Kinect tracking. The controller’s three buttons and joystick had specific actions configured to them as needed for each module.

After I conceptualized and storyboarded each module and got approval from the AMCOM CPO, I began the task of programming each myself. Mid-way through training module one the stakeholders made the decision to utilize professional programmers to compress the project schedule. Ultimately, I tasked WorldViz with only writing the lines of code for training module one and two, I completed the programming for the usage module myself. I managed and worked very closely with WorldViz and provided to them all the needed training materials for modules one and two.
Figure 4. Egocentric view of the animated pedagogical agent. Note. The platform is lowered, pit raised, and the movie screen is blank (i.e. black).

When designing the individual immersive VLEs I adopted Dr. Richard Mayer’s cognitive theory of multimedia learning (see Figure 5) for how people process information from multimedia messages (i.e. learning with technology). Mayer (2010) gives three assumptions concerning the theory:

1. “Dual channels: people have separate channels for processing verbal and visual material.” (p. 186)
2. “Limited capacity: people can process only small amounts of material in each channel at any one time.” (p. 186)
3. “Active processing: meaningful learning occurs when learners engage in appropriate cognitive processing during learning, such as attending to relevant material, organizing it into a coherent representation, and integrating it with relevant prior knowledge.” (p. 186)
There are also 12 basic research-based principles for designing learning environments, which contain words and pictures (i.e. multimedia). They are intended to be implemented in light of the cognitive theory of multimedia learning. I tried to design and present the training material inside the immersive VLEs around these principles.
### Table 5

**Principles of multimedia design**

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherence:</td>
<td>Reduce extraneous material</td>
<td>Videos were edited to include only essential training content</td>
</tr>
<tr>
<td>Signaling:</td>
<td>Highlight essential material</td>
<td>Key words and images flashed on screen as the agent spoke</td>
</tr>
<tr>
<td>Redundancy:</td>
<td>Do not add on-screen text to narrated animation</td>
<td>The trivia questions were given only as text</td>
</tr>
<tr>
<td>Spatial Contiguity</td>
<td>Place printed words next to corresponding graphics</td>
<td>N/A</td>
</tr>
<tr>
<td>Temporal Contiguity</td>
<td>Present corresponding narration and animation at the same time</td>
<td>Key words and images flashed on screen as the agent spoke</td>
</tr>
<tr>
<td>Segmenting:</td>
<td>Present animation in learner-paced segments</td>
<td>Three training modules and the trainee had video controls</td>
</tr>
<tr>
<td>Pre-training:</td>
<td>Provide pre-training on the main/key concepts</td>
<td>Received instructions and information before each module</td>
</tr>
<tr>
<td>Modality:</td>
<td>Present words as spoken text rather than printed text</td>
<td>Incorporated an animated pedagogical agent</td>
</tr>
<tr>
<td>Multimedia:</td>
<td>Present words and pictures rather than words alone</td>
<td>Videos had narration</td>
</tr>
<tr>
<td>Personalization:</td>
<td>Present words in conversational style rather than formal style</td>
<td>Incorporated conversational style into agent sound clips</td>
</tr>
<tr>
<td>Voice:</td>
<td>Friendly human rather than machine voice</td>
<td>Agent sound clips have no sound effects applied to them</td>
</tr>
<tr>
<td>Image</td>
<td>Adding speaker’s image to screen is not necessary</td>
<td>Agent spoke sometimes when he was not in view</td>
</tr>
</tbody>
</table>

*Notes.* Principles and definitions are from Mayer (2005), (2009), and (2010).

**Usage Module**

The first immersive VLE that the participants trained (i.e. learned) in was the usage module. The participants in this module become familiar with the VR system (e.g. HMD, Kinect, yoga mat, and controller), had the HMD properly fitted (e.g. position and
tightness) to their head, had the Kinect positioned for optimal tracking, took part in activities (e.g. audio listening, video watching, game play, etc.) within the immersive VLE that would later be seen and/or used in training module one and two, and asked questions as needed. See Training Module One and Training Module Two sections below for full details on the game play (i.e. action shooter trivia and jigsaw puzzle), VLE setup, interactions, resources used, etc.

During the action shooter portion of the usage module, the four trivia questions displayed in order were as follows ($Q =$ question; $A =$ Answer(s); $C =$ Choice(s)):

1. $Q$: Some common methods to reduce the conductive path are?
   - $A$: Primer, Sealant, Gaskets; $C$: Contaminants

2. $Q$: What should be done to military equipment to protect it against corrosion?
   - $A$: Cleaned, Inspected, Preserved; $C$: Unused

3. $Q$: Frequent corrosion _______ of military equipment helps in the fight to mitigate corrosion.
   - $A$: Inspections; $C$: Reviews, Walkthroughs, Protocols

4. $Q$: What are some techniques used to prevent and control the further progression of corrosion?
   - $A$: CPCs, Coatings, Sealants, Repairs; $C$: 

**Training Module One**

In training module, one the scene (see Figure 3) was further populated with the animated pedagogical agent (see Figure 4) and training material (i.e. passive and active media). The general idea for training module one was for the agent to guide the
participant through watching a series of educational corrosion based videos (displayed on the movie screen). The participants controlled the pace of the videos by using the joystick on the controller. The custom video controls were joystick up for pause, joystick down for play, joystick left for rewind, and joystick right for fast-forward. The ability to fast-forward, rewind, and pause the videos allowed the participant to learn at their own pace. As the videos were playing, key training points were displayed (e.g. flashed) onto the screen to reinforce their importance. Most of these key points dealt with questions on the exams. Requiring the participant to control parts of the content delivery process and interact within the VLE helped keep the participant fully engaged.

The second half of training module one was the action shooter trivia game. It began by tasking the participant to select a crosshair (i.e. mouse pointer) type (see Figure 6). Once game setup was complete, the game officially began by displaying a corrosion based trivia question on the movie screen. Then from the participants perched position on the platform (see Figure 7), they saw four blue balloons rising from the floor, each containing a possible answer to the trivia question. The participants’ next task was to identify and select the right answer(s) by shooting the correct balloon(s), thus answering the trivia question. A correct hit turned the balloon green and an incorrect hit turned the balloon red. If the participant failed to perform the task before the balloons had reached the ceiling the balloons become stationary and the correct balloon(s) (i.e. answer) began to flash. This conveyed the correct answer(s) to the participant and required them to participate before moving on to the next question. The combined time of video watching and game play was set at 15 minutes to limit the possibility of motion or cyber sickness. The VLE display basic gameplay attributes (e.g. user performance data), such as scoring
and time keeping. If the time limit ran out before the participant completed all 10 trivia questions, he or she had to proceed to training module two. The 10 trivia questions displayed in order were as follows \((Q = \text{question}; A = \text{Answer(s); } C = \text{Choice(s)}):\)

1. \(Q:\) What component of an electrochemical cell is generally easiest to control?
   - \(A:\) Electrolyte; \(C:\) Anode, Cathode, Electrons

2. \(Q:\) What does corrosion affect?
   - \(A:\) Equipment, Safety, Facilities, Readiness

3. \(Q:\) What lightweight material is considered highly susceptible to corrosion?
   - \(A:\) Magnesium; \(C:\) Carbon, Titanium, Graphite

4. \(Q:\) What common item is purposely designed to be an enclosed electrochemical cell?
   - \(A:\) Battery; \(C:\) Phone, Microwave, Furnace

5. \(Q:\) Corrosion costs billions of dollars a year and affects whom?
   - \(A:\) Government, Industry, Citizens, Soldiers

6. \(Q:\) What are some characteristics of corrosion?
   - \(A:\) Natural, Detectable, Relentless; \(C:\) Harmless

7. \(Q:\) What factors generally influence the rate of corrosion?
   - \(A:\) Humidity, Temperature; \(C:\) Weight, Wind Speed

8. \(Q:\) What are some common characteristics of cathodes?
   - \(A:\) Consume Electrons, Protected; \(C:\) Release Electrons, Sacrificial

9. \(Q:\) What are some common characteristics of anodes?
   - \(A:\) Release Electrons, Sacrificial; \(C:\) Consume Electrons, Protected

10. \(Q:\) What types of material corrode?
• A: Metals, Fabrics, plastics, Composites

**Figure 6.** Game play setup. *Note.* Displayed on the movie screen within the VLE.

**Figure 7.** Action shooter trivia game. *Note.* The platform is raised, pit lowered, the movie screen is displaying a trivia question, and the other two answer choices are not shown.
Training Module Two

In training module two, the scene was populated with the same agent but different training material (i.e. passive and active media). The general theme for this module was for the participant to select and manipulate (e.g. position) four randomly placed jigsaw puzzle pieces (i.e. images) in the VLE onto the movie screen to complete the puzzle (see Figure 8). When all the individual puzzle pieces were placed in their correct location the full puzzle image (i.e. photo) revealed was a high resolution zoomed in (i.e. close-up) image of a type of corrosion. I created the zoomed in image by taking (i.e. cropping) it from an even higher resolution and zoomed out photo (see Figure 9). I divided (i.e. cropped) the zoomed in image into four quarters to make the individual jigsaw puzzle pieces (see Figure 10). If the participants failed to place the four puzzle pieces into their correct locations or the timer ran out Vizard would automatically move the pieces into their correct locations to reveal the full puzzle image. During each of the revealing processes the agent told the participant the definition of that images’ corrosion type.

There were six separate puzzles and the corrosion types were a) crevice, b) general surface, c) pitting, d) galvanic, e) intergranular or exfoliation, and f) filiform.

After each puzzle, an educational video based on that images’ corrosion type would play on the movie screen. The same video controls used in training module one allowed the participants the opportunity to control the pace of the videos. Once again the ability to fast-forward, rewind, and pause the videos allowed the participant to learn at their own pace. Training module two also required the participant to control parts of the content delivery process and interact within the VLE thus helping to keep the participant fully engaged. The combined time of video watching and game play was set at 15
minutes to limit the possibility of motion or cyber sickness. The VLE displayed basic gameplay attributes, (e.g. user performance data), such as scoring and time keeping. Once the time limit ran out or the participant completed all six puzzles, he or she proceeded with the exit questionnaire and interview.

Figure 8. Locations of puzzle pieces. Note. The platform is raised, pit lowered, the movie screen is displaying four quadrants to place the individual puzzle pieces into, and the four individual puzzle pieces are shown left/right and staggered.

Figure 9. Completed puzzle. Zoomed out (left) and zoomed in (right).
Figure 10. Individual puzzle pieces. Pieces are labeled as top left (TL), top right (TR), bottom left (BL), and bottom right (BR). Filiform corrosion.

Procedure and Setting

I coordinated the research site locations with the AMCOM CPO. However, I had no control or influence over scheduling the routine CPC training courses, recruiting the trainees, or insuring that the same instructor provided the lecture-based multimedia training at each research site. The CPC training courses can take place anywhere in the world. However, all sites visited were located within the contiguous United States. The setting was normally a typical classroom or conference room (tables, chairs, digital projector, etc.). There was moderate control of the variables because the research study did not take place in a laboratory setting or in a full operational setting. The following is the list of the research sites (first to last):

1. 14 March 2013, Redstone Arsenal, Huntsville, AL (focus group – part two)
2. 23 April 2013, Redstone Arsenal, Huntsville, AL (focus group – part one)
3. 18 June 2013, AMCOM Corrosion Program Office Corrosion Monitors Course, Redstone Arsenal, Huntsville, AL

4. 2 August 2013, Rhode Island Army National Guard, D (Delta) Company, 1st Battalion, 126th Aviation Regiment, Quonset Armory, North Kingston, RH

5. 20 August 2013, AMCOM Corrosion Program Office Corrosion Monitors Course, Redstone Arsenal, Huntsville, AL

6. 6 September 2013, Tennessee Army National Guard, Army Aviation Support Facility #3, Jackson, TN

7. 7 September 2013 (morning), Tennessee Army National Guard, Army Aviation Support Facility #3, Jackson, TN

8. 7 September 2013 (afternoon), Tennessee Army National Guard, Army Aviation Support Facility #3, Jackson, TN

9. 1 October 2013 (morning), U.S. Army, 4th Battalion 160th SOAR(A), Joint Base Lewis-McChord, WA

10. 1 October 2013 (afternoon), U.S. Army, 4th Battalion, 160th SOAR(A), Joint Base Lewis-McChord, WA

11. 2 October 2013, U.S. Army, 4th Battalion 160th SOAR(A), Joint Base Lewis-McChord, WA

12. 3 October 2013, U.S. Army, 4th Battalion 160th SOAR(A), Joint Base Lewis-McChord, WA

13. 22 October 2013 (morning), U.S. Army, 1st and 2nd Battalion, 160th SOAR(A), Fort Campbell, KY
14. 22 October 2013 (afternoon), U.S. Army, 1st and 2nd Battalion, 160th SOAR(A), Fort Campbell, KY

15. 23 October 2013, U.S. Army, 1st and 2nd Battalion, 160th SOAR(A), Fort Campbell, KY

16. 1 November 2013, U.S. Army, 90th Aviation Support Battalion, Naval Air Station Joint Reserve Base, Fort Worth, TX

For tracking and correlation purposes, each participant in the investigational group created a unique identifier when signing their consent form. They then proceeded to write it on each instrument (e.g. questionnaire, interview, and exam) that they completed (i.e. filled out). The unique identifier was one of the following options:

- last four digits of your social security number + favorite sports team
- last four digits of your phone number + street you grew up on
- last four digits of your zip code + pets name

Focus Group

The procedure for part one and two of the focus group were different. In part one, of the focus group I coordinated with the AMCOM CPO to attend one of their scheduled routine CPC training courses. Before the students arrived, I placed a manila envelope at each seat containing a copy of the informed consent, questionnaires, and interview script. I then proceeded to give a PowerPoint presentation discussing the research study and focus group in general, during which I ensured students that participation in the research study would play no role in their performance and passing of the CPC training course. This allowed the students time to review the documents in the folder and decide on their
own if they would like to volunteer (i.e. coercion prevention). After the completion of the presentation, I collected the envelopes and differentiated the volunteers (i.e. participants) from non-volunteers by signed consent forms. I took further preventative measures against coercion by making the students aware that refusal or withdrawal from the study would not affect their relationship with UAB or the AMCOM CPO.

The first activity completed was the distribution of the pre-exam. Once completed by the participants I collected all the exams. No discussion or input concerning the correct answers took place. The group discussions concerning the questionnaires and interview script were completed as free time was available throughout the routine CPC training course.

In part two, of the focus group I also coordinated with the AMCOM Corrosion Office but this time for a list of names and contact information for corrosion subject matter experts and the CPC training course instructors. I emailed each individual an electronic copy of the informed consent along with written details concerning the research study and focus group in general. After receiving the signed consent form, I then emailed that participant with the electronic copies of the pre- and post- exams. They were allowed to review and redline (e.g. mark-up, suggest changes, comment, etc.) the exams for one week. After receiving all the redlined exams, I incorporated the necessary changes and submitted an amendment to UAB’s IRB office for approval.

**Formal Research Study**

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 by the graduate study committee. The outlined procedure for the formal research study is as follows:
1. I coordinated with the AMCOM CPO to attend one of their scheduled routine CPC training courses.

2. Before the start of the CPC training course, I placed a manila envelope, containing a copy of the informed consent and entrance questionnaire at each student’s seat.

3. 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.

4. After collecting all the envelopes, I differentiated the volunteers (i.e. participants) from non-volunteers by signed consent forms and fully filled out questionnaires.

5. 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 I collected all the pre-exams.

6. While the pre-exam was being administered I entered all the unique identifiers from the consent forms into a random number generator and selected (i.e. randomly assigned) one or two participants for the investigational group based on class size and time constraints. I then analyzed their individual entrance questionnaires to ensure they met the inclusion and exclusion criteria. If not, I would place that participant into the control group and then randomly generate another participant for the investigational group. This process continued as needed.
7. As the control group continued with the lecture-based multimedia instruction (i.e. routine CPC training), the investigational group began the VR-based multimedia instruction (i.e. immersive VLE training) in a separate location. Only one VR system was available so only one participant at a time completed the training.

8. Once each participant of the investigational group completed all three modules (e.g. usage and training modules one and two) during the VR-based multimedia instruction, an exit questionnaire was completed and an interview conducted.

9. Once all the participants from both groups received instruction (i.e. training), they reconvened to take the post-exam.

10. Approximately four weeks after initial contact with the participants, I would send them an email containing a hyperlink and the password to the long-term retention exam.

11. Approximately one week after I sent the initial email, I would send a reminder email to complete the exam.
RESULTS

Focus Group

The sample for part one of the focus group consisted of eight participants (eight males) with a mean age of 37.88 years ($SD = 8.43$), of which 63 percent ($N = 5$) had previously attended an AMCOM CPC course. Two of the eight completed pre-exams were removed prior to scoring due to incorrect test taking procedures. The possible scoring range on the pre-exam was 0 – 100 percent, where higher scores indicated higher levels of CPC declarative knowledge. The mean score on the pre-exam for part one of the focus group was 59.67 ($SD = 11.66$).

The pre-, post-, and long-term retention exams were sent to nine corrosion subject matter experts and/or instructors at the AMCOM CPO for part two of the focus group. Four individuals provided feedback (e.g. comments, suggestions, corrections, etc.).

Formal Research Study

*Descriptive Statistics*

*Sample Demographics*

The sample for the formal research study consisted of 140 participants (four females) with a mean age of 29.64 and median age of 28.00 years ($SD = 8.03$). Of which, 32.14 percent ($N = 45$) had previously attended an AMCOM CPC course, 68.57 percent ($N = 96$) had previously heard of VR, AR, and/or VE, and 21.43 percent ($N = 30$) had prior experience(s) with immersive VR (see Table 6).
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, AR, and/or VE ($M = 1.95$) (see Table 7).

Table 6

Sample frequencies

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Gender (count)</th>
<th>Previously attended an AMCOM CPC course (count)</th>
<th>Previously heard of VR, AR, and/or VE (count)</th>
<th>Prior immersive VR usage (count)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N = 140$</td>
<td>29.64</td>
<td>Male/Female</td>
<td>136/4</td>
<td>82/45/8</td>
<td>107/30/3</td>
</tr>
<tr>
<td>Mean</td>
<td>29.64</td>
<td>Male/Female</td>
<td>136/4</td>
<td>82/45/8</td>
<td>107/30/3</td>
</tr>
<tr>
<td>Median</td>
<td>28.00</td>
<td>Male/Female</td>
<td>136/4</td>
<td>82/45/8</td>
<td>107/30/3</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>8.03</td>
<td>Male/Female</td>
<td>136/4</td>
<td>82/45/8</td>
<td>107/30/3</td>
</tr>
<tr>
<td>Min/Max</td>
<td>19/59</td>
<td>Male/Female</td>
<td>136/4</td>
<td>82/45/8</td>
<td>107/30/3</td>
</tr>
</tbody>
</table>

Notes. C = control and I = investigational.

Table 7

Entrance questionnaire Likert-item means

<table>
<thead>
<tr>
<th></th>
<th>Familiarity with CPC</th>
<th>Familiarity with computers and smart phones</th>
<th>Computers and smart phone usage</th>
<th>Video game usage</th>
<th>Familiarity with VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N = 140$</td>
<td>Mean</td>
<td>3.27</td>
<td>3.86</td>
<td>4.41</td>
<td>3.29</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>.912</td>
<td>.715</td>
<td>.599</td>
<td>.978</td>
</tr>
</tbody>
</table>

Notes. Each question was a five-level Likert item (Vagias, 2006). See APPENDIX B
The possible scoring range on the pre- and post-exams was 0 – 100 percent. The sample mean score on the 22 question pre-exam was 55.85 percent ($SD = 12.85$), and 65.55 percent ($SD = 11.08$) on the 17 common questions (see Figure 11). The sample mean score on the 22 question post-exam was 63.60 percent ($SD = 13.08$), and 73.90 percent ($SD = 11.00$) on the 17 common questions (see Figure 12). The sample mean score on the 22 question long-term retention exam was 64.42 percent ($SD = 11.72$), and 74.14 percent ($SD = 10.73$) on the 17 common questions (see Figure 13).

*Figure 11.* Sample frequencies - pre-exam. *Note.* Only 17 common exam questions used.
Figure 12. Sample frequencies - post-exam. Note. Only 17 common exam questions used.

Figure 13. Sample frequencies - long-term retention exam. Note. Only 17 common exam questions used.
Learning Outcome

One hundred percent of the total sample (see Table 6) completed the pre- and post-exams, which evaluated the dependent variable of learning (position one).

The control group consisted of 115 participants (four females) with a mean age of 29.50 and median age of 28.00 years ($SD = 8.04$). Of which, 33.04 percent ($N = 38$) had previously attended an AMCOM CPC course, 69.57 percent ($N = 80$) had previously heard of VR, AR, and/or VE, and 21.74 percent ($N = 25$) had prior experience(s) with immersive VR (see Table 8). The investigational group consisted of 25 participants (zero females) with a mean age of 30.32 and median age of 30.00 years ($SD = 8.09$). Of which, 28.00 percent ($N = 7$) had previously attended an AMCOM CPC course, 64.00 percent ($N = 16$) had previously heard of VR, AR, and/or VE, and 20.00 percent ($N = 5$) had prior experience(s) with immersive VR (see Table 8).

The control group 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 ($M = 4.39$), sometimes to often play video games ($M = 3.28$), and none to slightly familiar with VR, AR, and/or VE ($M = 1.93$) (see Table 9). The investigational group as a whole was somewhat to moderately familiar with CPC ($M = 3.28$ and computers and/or smart phones ($M = 3.84$), often to always use computers and/or smart phones ($M = 4.48$), sometimes to often play video games ($M = 3.36$), and none to slightly familiar with VR, AR, and/or VE ($M = 1.95$) (see Table 9).
Table 8

*Group frequencies - learning outcome*

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Gender (count)</th>
<th>Previously attended an AMCOM CPC course (count)</th>
<th>Previously heard of VR, AR, and/or VE (count)</th>
<th>Prior immersive VR usage (count)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C, N = 115</td>
<td>Mean 29.50</td>
<td>Median 28.00</td>
<td>Std. Deviation 8.04</td>
<td>Min/Max 20/59</td>
<td>Male/Female 111/4</td>
</tr>
<tr>
<td></td>
<td>Male/Female</td>
<td></td>
<td></td>
<td></td>
<td>No/Yes/Unsure 65/38/7</td>
</tr>
<tr>
<td>I, N = 25</td>
<td>Mean 30.32</td>
<td>Median 30.00</td>
<td>Std. Deviation 8.09</td>
<td>Min/Max 19/50</td>
<td>Male/Female 25/0</td>
</tr>
<tr>
<td></td>
<td>Male/Female</td>
<td></td>
<td></td>
<td></td>
<td>No/Yes/Unsure 17/7/1</td>
</tr>
</tbody>
</table>

*Notes.* C = control group and I = investigational group.

Table 9

*Entrance questionnaire Likert-item means by group - learning outcome*

<table>
<thead>
<tr>
<th>Group</th>
<th>Familiarity with CPC</th>
<th>Familiarity with computers and smart phones</th>
<th>Computers and smartphone usage</th>
<th>Video game usage</th>
<th>Familiarity with VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>C, N = 115</td>
<td>Mean 3.27</td>
<td><strong>3.86</strong></td>
<td>4.39</td>
<td>3.28</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation .90</td>
<td>.75</td>
<td>.62</td>
<td>.95</td>
<td>.94</td>
</tr>
<tr>
<td>I, N = 25</td>
<td>Mean 3.28</td>
<td>3.84</td>
<td><strong>4.48</strong></td>
<td>3.36</td>
<td><strong>1.95</strong></td>
</tr>
<tr>
<td></td>
<td>Std. Deviation .98</td>
<td>.55</td>
<td>.51</td>
<td>1.11</td>
<td>.93</td>
</tr>
</tbody>
</table>

*Notes.* Each question was a five-level Likert item (Vagias, 2006). See APPENDIX B
The control groups’ mean exam score increased by 11.17 percent (22 exam questions) and 11.45 percent (17 common exam questions) respectively after the lecture-based multimedia instruction (see Table 10). The investigational groups’ mean exam score increased by 26.20 percent (22 exam questions) and 18.47 percent (17 common exam questions) respectively after the VR-based multimedia instruction (see Table 10). 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 10

*Exam score analysis by group - learning outcome*

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-Exam (22Q)</th>
<th>Post-Exam (22Q)</th>
<th>Pre-Exam (17Q)</th>
<th>Post-Exam (17Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C, (N = 115)</td>
<td>Mean 55.61</td>
<td>61.82</td>
<td>65.26*</td>
<td>72.73*</td>
</tr>
<tr>
<td></td>
<td>Median 54.55</td>
<td>59.09</td>
<td>63.64</td>
<td>72.73</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation 13.02</td>
<td>12.31</td>
<td>11.41</td>
<td>10.73</td>
</tr>
<tr>
<td></td>
<td>Min/Max 22.73/</td>
<td>22.73/</td>
<td>36.36/</td>
<td>45.45/</td>
</tr>
<tr>
<td>I, (N = 25)</td>
<td>Mean 56.91</td>
<td>71.82</td>
<td>66.91*</td>
<td>79.27*</td>
</tr>
<tr>
<td></td>
<td>Median 59.09</td>
<td>72.73</td>
<td>68.18</td>
<td>77.27</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation 12.25</td>
<td>13.64</td>
<td>9.51</td>
<td>10.98</td>
</tr>
<tr>
<td></td>
<td>Min/Max 27.27/</td>
<td>31.82/</td>
<td>40.91/</td>
<td>50.00/</td>
</tr>
</tbody>
</table>

*Notes. *see Figure 14, Figure 15, Figure 16, and Figure 17. 22Q = 22 questions and 17Q = 17 questions.*
Figure 14. Group pre-exam boxplot - learning outcome. Note. Only 17 common exam questions used.

Figure 15. Group post-exam boxplot - learning outcome. Note. Only 17 common exam questions used.
Figure 16. Group pre-exam population pyramid - learning outcome. Note. Only 17 common exam questions used.
Figure 17. Group post-exam population pyramid - learning outcome. Note. Only 17 common exam questions used.
**Long-term Retention Outcome**

The email containing the link to the exam was successfully sent to 139 of the participants. Only 20.86 percent ($N = 29$) of the total sample (see Table 6) completed the long-term retention exam, which were used to evaluate the dependent variable of long-term retention (position two).

There was 19 participants (0 females) from the control group with a mean age of 31.05 and median age of 29.00 years ($SD = 8.63$). Of which, 26.32 percent ($N = 5$) had previously attended an AMCOM CPC course, 68.42 percent ($N = 13$) had previously heard of VR, AR, and/or VE, and 26.32 percent ($N = 5$) had prior experience(s) with immersive VR (see Table 11). There was 10 participants (0 females) from the investigational group with a mean age of 33.60 and median age of 33.50 years ($SD = 7.66$). Of which, 30.00 percent ($N = 3$) had previously attended an AMCOM CPC course, 80.00 percent ($N = 8$) had previously heard of VR, AR, and/or VE, and 40.00 percent ($N = 4$) had prior experience(s) with immersive VR (see Table 11).

The control group as a whole was somewhat to moderately familiar ($M = 3.11$) with CPC, somewhat to moderately familiar ($M = 3.89$) with computers and/or smart phones, often to always ($M = 4.58$) use computers and/or smart phones, rarely to sometimes ($M = 2.84$) play video games, and none to slightly familiar ($M = 1.95$) with VR, AR, and/or VE (see Table 12). The investigational group as a whole was somewhat to moderately familiar ($M = 3.60$) with CPC, somewhat to moderately familiar ($M = 3.80$) with computers and/or smart phones, often to always ($M = 4.60$) use computers and/or smart phones, sometimes to often ($M = 3.30$) play video games, and slightly to somewhat familiar ($M = 2.40$) with VR, AR, and/or VE (see Table 12).
Table 11

*Group frequencies - long-term retention outcome*

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Gender (count)</th>
<th>Previously attended an AMCOM CPC course (count)</th>
<th>Previously heard of VR, AR, and/or VE (count)</th>
<th>Prior immersive VR usage (count)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C</strong></td>
<td>31.05</td>
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<tr>
<td><strong>N = 19</strong></td>
<td>29.00</td>
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<td></td>
<td></td>
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<td>Mean</td>
<td>31.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>29.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>8.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min/Max</td>
<td>21/54</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male/Female</td>
<td>19/0</td>
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</tr>
<tr>
<td>No/Yes/Unsure</td>
<td>14/5/0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>33.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>N = 10</strong></td>
<td>33.50</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean</td>
<td>33.60</td>
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</tr>
<tr>
<td>Median</td>
<td>33.50</td>
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</tr>
<tr>
<td>Std. Deviation</td>
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<td>Min/Max</td>
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<tr>
<td>Male/Female</td>
<td>10/0</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>No/Yes/Unsure</td>
<td>6/3/1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Notes.* C = control and I = investigational.

Table 12

*Entrance questionnaire Likert-item means by group - long-term retention outcome*

<table>
<thead>
<tr>
<th>Group</th>
<th>Familiarity with CPC</th>
<th>Familiarity with computers and smart phones</th>
<th>Computers and smart phone usage</th>
<th>Video game usage</th>
<th>Familiarity with VR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C</strong></td>
<td>3.11</td>
<td>3.89</td>
<td>4.58</td>
<td>2.84</td>
<td>1.95</td>
</tr>
<tr>
<td><strong>N = 19</strong></td>
<td>.99</td>
<td>.57</td>
<td>.51</td>
<td>.77</td>
<td>.85</td>
</tr>
<tr>
<td>Mean</td>
<td>3.60</td>
<td>3.80</td>
<td>4.60</td>
<td>3.30</td>
<td>2.40</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>3.60</td>
<td>3.80</td>
<td>4.60</td>
<td>3.30</td>
<td>2.40</td>
</tr>
<tr>
<td><strong>N = 10</strong></td>
<td>.52</td>
<td>.79</td>
<td>.52</td>
<td>1.25</td>
<td>.84</td>
</tr>
<tr>
<td>Mean</td>
<td>3.60</td>
<td>3.80</td>
<td>4.60</td>
<td>3.30</td>
<td>2.40</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>.52</td>
<td>.79</td>
<td>.52</td>
<td>1.25</td>
<td>.84</td>
</tr>
</tbody>
</table>

*Notes.* Each question was a five-level Likert item (Vagias, 2006). See APPENDIX B
The control groups’ mean exam score decreased by 2.17 percent (22 exam questions) and 3.12 percent (17 common exam questions) respectively since taking post-exam (see Table 13). The investigational groups’ mean exam score decreased by 18.55 percent (22 exam questions) and 10.78 percent (17 common exam questions) respectively since taking post-exam (see Table 13). The majority of the sample (N = 29) showed a decrease in mean score from post-exam to long-term retention exam (17 common exam questions), however, 31.03 percent (N = 9) of the sample showed an increase.

The average time (M = 00:17:08) to complete the long-term retention exam for participants who had the increase in mean scores was 32.98 percent longer than the participants who had a decrease (M = 00:11:29). Further breakdown shows that control group participants (N = 6, M = 00:19:50) took 40.92 percent longer to complete the long-term retention exam than the investigational group participants (N = 3, M = 00:11:43).

Table 13

*Exam score analysis by group - long-term retention*

<table>
<thead>
<tr>
<th>Group</th>
<th>Post-Exam (22Q)</th>
<th>Long-term Retention Exam (22Q)</th>
<th>Post-Exam (17Q)</th>
<th>Long-term Retention Exam (17Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Mean 66.99</td>
<td>65.55</td>
<td>77.75*</td>
<td>75.36*</td>
</tr>
<tr>
<td></td>
<td>Median 68.18</td>
<td>63.64</td>
<td>77.27</td>
<td>72.73</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation 9.80</td>
<td>12.88</td>
<td>8.42</td>
<td>11.37</td>
</tr>
<tr>
<td></td>
<td>Min/Max 50.00/86.36</td>
<td>40.91/81.82</td>
<td>63.64/90.91</td>
<td>90.91/54.55</td>
</tr>
<tr>
<td>N = 19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Mean 75.00</td>
<td>62.27</td>
<td>80.00*</td>
<td>71.82*</td>
</tr>
<tr>
<td></td>
<td>Median 77.27</td>
<td>59.09</td>
<td>81.82</td>
<td>72.73</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation 13.25</td>
<td>9.35</td>
<td>11.58</td>
<td>9.53</td>
</tr>
<tr>
<td></td>
<td>Min/Max 50.00/90.91</td>
<td>45.45/77.27</td>
<td>59.09/90.91</td>
<td>54.55/86.36</td>
</tr>
<tr>
<td>N = 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Notes. 22Q = 22 questions and 17Q = 17 questions.*
Usability Evaluation

The investigational group participants ($N = 25$) provided the usability evaluation (see Table 15). Eighty-eight percent believed that an immersive VLE was an efficient method of training for CPC. Seventy-two percent would like additional training sessions in the immersive VLE. Seventy-two percent would prefer a learning environment, for CPC training; of a combination of classroom lecture-based and VR-based multimedia instruction (see Table 14).

As a whole the investigational groups’ mean ratings for engagement items were good to very good, satisfaction items were good to very good, comfort items were fair to very good, ease of use items were good to very good, ease of learning items were good to excellent (see Table 15). As a whole the investigational groups’ mean ratings for content items were disagree to strongly agree and hardware/software items disagree to agree (see Table 15).

Table 14

Exit questionnaire analysis - usability evaluation

<table>
<thead>
<tr>
<th>Response</th>
<th>Efficient Method of Training</th>
<th>Additional Training Sessions</th>
<th>Preferred Learning Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>Percent</td>
<td>$N$</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
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<td>4</td>
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<tr>
<td>Yes</td>
<td>22</td>
<td>88</td>
<td>18</td>
</tr>
<tr>
<td>Unsure</td>
<td>2</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Live instructor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immersive VLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination of both</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. See APPENDIX B.
Table 15

*Exit questionnaire Likert-item analysis - usability evaluation*

<table>
<thead>
<tr>
<th>Item</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
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<td>Engagement 1</td>
<td>25</td>
<td>3.64</td>
<td>4.00</td>
<td>.95</td>
</tr>
<tr>
<td>Engagement 2</td>
<td>25</td>
<td>3.76</td>
<td>4.00</td>
<td>1.05</td>
</tr>
<tr>
<td>Engagement 3</td>
<td>25</td>
<td>3.68</td>
<td>4.00</td>
<td>.99</td>
</tr>
<tr>
<td>Engagement 4</td>
<td>25</td>
<td>3.96</td>
<td>4.00</td>
<td>.98</td>
</tr>
<tr>
<td>Satisfaction 1</td>
<td>25</td>
<td>3.72</td>
<td>4.00</td>
<td>1.02</td>
</tr>
<tr>
<td>Satisfaction 2</td>
<td>25</td>
<td>4.00</td>
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<td>Satisfaction 4</td>
<td>25</td>
<td>3.92</td>
<td>4.00</td>
<td>1.04</td>
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<td>Comfort 1</td>
<td>25</td>
<td>2.60</td>
<td>3.00</td>
<td>1.22</td>
</tr>
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<td>3.16</td>
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<tr>
<td>Ease of use 1</td>
<td>25</td>
<td>3.64</td>
<td>4.00</td>
<td>.99</td>
</tr>
<tr>
<td>Ease of use 2</td>
<td>25</td>
<td>3.60</td>
<td>4.00</td>
<td>1.08</td>
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<td>3.56</td>
<td>4.00</td>
<td>1.08</td>
</tr>
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<td>3.64</td>
<td>4.00</td>
<td>1.08</td>
</tr>
<tr>
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<td>3.84</td>
<td>4.00</td>
<td>1.03</td>
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<td>Ease of learning 2</td>
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<td>3.96</td>
<td>4.00</td>
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</tr>
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<td>4.00</td>
<td>4.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Ease of learning 4</td>
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<td>4.16</td>
<td>4.00</td>
<td>.99</td>
</tr>
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<td>Content 1</td>
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</tr>
<tr>
<td>VLE 3</td>
<td>25</td>
<td>3.68</td>
<td>4.00</td>
<td>.95</td>
</tr>
<tr>
<td>VLE 4</td>
<td>25</td>
<td>2.96</td>
<td>3.00</td>
<td>.98</td>
</tr>
<tr>
<td>VLE 5</td>
<td>25</td>
<td>3.24</td>
<td>3.00</td>
<td>1.16</td>
</tr>
<tr>
<td>VLE 6</td>
<td>25</td>
<td>3.64</td>
<td>4.00</td>
<td>.81</td>
</tr>
<tr>
<td>Seriousness</td>
<td>23</td>
<td>4.70</td>
<td>5.00</td>
<td>.63</td>
</tr>
</tbody>
</table>

*Notes.* Each question was a five-level Likert item (Vagias, 2006). See APPENDIX B
Inferential Statistics

Group Analysis

Independent samples $t$-tests were conducted to compare the entrance questionnaire mean scores (see Table 9) between the control and investigational group participants. Between the two groups there was no significant difference in scores on; familiarity with CPC, $t(138) = -.052, p = .959$, two-tailed with investigational group ($M = 3.28, SE = .196$) scoring higher than control group ($M = 3.27, SE = .084$), familiarity with computers and/or smart phones, $t(138) = -.132, p = .895$, two-tailed with control group ($M = 3.86, SE = .070$) scoring higher than investigational group ($M = 3.84, SE = .111$), computer and/or smart phone usage, $t(138) = -.670, p = .504$, two-tailed with investigational group ($M = 4.48, SE = .102$) scoring higher than control group ($M = 4.39, SE = .058$), video game usage, $t(138) = -.378, p = .706$, two-tailed with investigational group ($M = 3.36, SE = .223$) scoring higher than control group ($M = 3.28, SE = .089$), and VR, AR, VE experience, $t(138) = -.539, p = .591$, two-tailed with investigational group ($M = 2.04, SE = .175$) scoring higher than control group ($M = 1.93, SE = .089$).

Chi-square tests of independence were conducted to examine the entrance questionnaire frequency responses (see Table 8) between the control and investigational group participants. The relation between group type and frequency of previously attending an AMCOM CPC course was not significant, $X^2 (2, N = 135) = .720, p = .698$. The relation between group type and frequency of previously hearing about VR, AR, VE was not significant, $X^2 (2, N = 140) = .357, p = .836$. The relation between group type and frequency of previously attending an AMCOM CPC course was not significant, $X^2 (2, N = 140) = .520, p = .771$. 

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Learning Outcome

An independent samples t-test was conducted to compare the pre-exam scores (only 17 common exam questions) between the control and investigational group participants. There was no significant difference in score between the two groups, \( t(138) = -.674, p = .501 \), two-tailed with investigational group (\( M = 66.91, SE = 1.90 \)) scoring higher than control group (\( M = 65.26, SE = 1.06 \)). This difference, -1.65, 95% CI [-6.50, 3.19] represents a small-sized effect, \( d = .14 \).

A one-way analysis of covariance (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, \( F(1, 136) = .33, p = .568 \) (see Figure 18). The ANCOVA was significant, \( F(1, 137) = 7.61, p = .007 \) (see Table 16).

Table 16

Analysis of co-variance for exam scoring by instruction type

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Exam</td>
<td>3,644.15</td>
<td>1</td>
<td>3,644.15</td>
<td>40.56</td>
<td>.000</td>
</tr>
<tr>
<td>Instruction Type</td>
<td>684.01</td>
<td>1</td>
<td>684.05</td>
<td>7.61</td>
<td>.007</td>
</tr>
<tr>
<td>Error</td>
<td>12,307.90</td>
<td>137</td>
<td>89.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>781,314.05</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. R Squared = .269 (Adjusted R Squared = .258)
Follow-up tests were conducted to evaluate pairwise differences among the adjusted means for instruction type level. The Least Significant Difference procedure was used to control for Type I error across the two pairwise comparisons ($\alpha = .05/2 = .025$). The results showed investigational group participants ($M = 78.64$) had significantly higher exam scores, controlling for the effect of their pre-exam, than control group participants ($M = 72.86$). The effect size for the significant adjusted mean difference was .61 (see Table 17).

Table 17

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Adjusted Mean</th>
<th>Adjusted Mean Differences (adj $M_i$ - adj $M_j$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>72.73</td>
<td>72.86</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>79.27</td>
<td>78.64</td>
<td>5.78*</td>
</tr>
</tbody>
</table>

Notes. *$p = .007$
A power analysis on the unequal group sample sizes of 115 and 25 achieved 74 percent power to detect a difference of 5.71 with two repeated measurements having a Compound Symmetry covariance structure when $SD = 11.41$ (see Table 10), the correlation between observations on the same subject is 0.50, and the alpha level is 0.05.

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 10 and Figure 19).
Figure 19. 2 X 2 Interaction plot - learning outcome. Note. Only 17 common exam questions used.
Long-term Retention Outcome

A power analysis on the unequal group sample sizes of 19 and 10 achieved 57 percent power to detect a difference of 5.70 with three repeated measurements having a Compound Symmetry covariance structure when $SD = 8.42$ (see Table 13), the correlation between observations on the same subject is 0.50, and the alpha level is 0.05.

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 three time periods (i.e. pre-, post-, and long-term retention exam). There was no significant interaction between instruction type and time, Wilks’ Lambda = .93, $F(2, 26) = .95$, $p = .400$, partial eta squared = .07. There was a significant main effect for time, Wilks’ Lambda = .61, $F(2, 26) = 8.39$, $p < .001$, partial eta squared = .39, with both group participants showing an increase in exam scores from time points one to two and a decrease from points two to three (see Table 13 and Figure 20).
Figure 20. 2 X 3 Interaction plot - long-term retention outcome. Note. Only 17 common exam questions used.
Qualitative Analysis

Exit Interview

The following is a sample of the direct quotes given by participants after receiving the VR-based multimedia instruction.

- What did you like, if anything about the immersive VLE?

  *I felt more immersed in the learning process.*

  *It was closer to hands on while still being in a classroom.*

  *It wasn’t the usual death by PowerPoint, it was new and I enjoyed it.*

- What did you dislike, if anything, about the immersive VLE?

  *I think a live instructor for Q&A would be nice.*

  *The equipment itself is uncomfortable.*

- What did you find frustrating, if anything, about this training style?

  *Controlling the crosshair with the Bluetooth joystick.*

  *The style was good. The equipment was frustrating.*

- What did you find engaging, if anything, about this training style?

  *The games force the user to interact with the training and will probably relate well to younger users.*

  *I felt that the training was more one on one.*

- Did you get a sense of presence and do you think that effects the quality of the training?

  *I feel like all learning should give the learner a presence of being there or learning is not as effective.*
You can still tell it’s not 100% but is not distracting in the sense. It was a different and involving experience.

- Do you have any other comments and/or suggestions?

This type of training may have a use but I don’t think it is for this type of training.

Better features for users (joystick, HMD).

Observations

At each research site, I observed that the instructors themselves agreed upon who would led each routine training course and the actual training time was dependent upon that instructor. In general, I observed that active and fulltime soldiers, U.S. Army and Reserves, were more interested, active, and willing to participate in the research study. While giving my recruitment presentation I observed that the phrase death by PowerPoint normally triggered negative (e.g. moans, eye rolling, etc.) reactions (verbally and physically). Participants generally seemed more patient and thorough while taking pre-exam over post-exam. The lecture-based training generally lasted two to three hours (including breaks).

During VR-based multimedia instruction, I observed only one participant who used the fast-forward option during the video watching portions. Most often, the participants watched the videos from start to finish without using any of the video controls. The two low mean comfort scores in Table 15 are most likely due to the modifications to the HMD (i.e. OS3D integration) and the temporary Bluetooth disconnections between the controller and PC, which normally happened only during training module one. I also observed that after completing the VR-based training and a short amount of time many of the participants would find me and suggest future training
modules and VR training applications. During the training, I observed a mixture of negative and positive reactions from the participants. Some of the verbal reactions were cheering during the gameplay portions and some of the physically reactions were acts of celebration (e.g. fist pump, smiles, etc.) and/or acts of boredom (e.g. slumping, fidgeting, etc.). Finally, I believe I observed participants’ full immersion during the majority of the VR-based training because often-other soldiers would enter/leave the training area or speak to the participant, which most often resulted in no reaction or reply from the participant.
CONCLUSION, DISCUSSION, and RECOMMENDATIONS

Conclusions

This dissertation has compared 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 and long-term retention of basic CPC theories and principles in U.S. Army soldiers after taking an AMCOM CPO’s CPC training course. Additionally, it has provided a usability evaluation of the VR system. By returning to the research questions posed at the beginning of this study and from the data analysis, it is now possible to state the following conclusions.

1. Immersive VLEs are a better form of multimedia instruction for U.S. Army soldiers, in terms of learning for basic CPC theories and principles than instructor-led lectures with PowerPoint.

2. Instructor-led lectures with PowerPoint are a better form of multimedia instruction for U.S. Army soldiers, in terms of long-term retention for basic CPC theories and principles than immersive VLEs. However, this is likely due to small sample size and outlying scores.

3. VR-based and lecture-based multimedia instruction both increase U.S. Army soldiers’ general declarative knowledge of CPC theories and principles. However, immersive VLEs produce higher gains.

4. Using immersive VR for CPC training/education is enjoyable, satisfying, and can be an effect way to learn and condense overall classroom training time.
5. The HMD and controller need replaced or upgraded to improve user comfort.

6. Immersive VR is a promising educational tool to transition from passive learning to active learning.

7. Lecture-based instruction continues to be a cheaper and more efficient method for a large group of learners while VR-based instruction advocates individual training.

8. The introduction of technology, such as immersive VR can be used a means of motivating an individual to participate fully in training with the purpose of acquiring declarative knowledge.

9. The VR system created and used is low-cost, saleable, and portable, thus meeting the CPO requirements.

10. Immersive VR should augment or complement live instruction.

Discussions of the Results

As stated earlier, defining VR/VE can be very difficult for a variety of reasons. There are no fully accepted standards/guidelines for defining VR, let alone the VR systems specific immersion level, and published research often uses VR and VE interchangeably. Therefore, finding previously published studies, which support all conclusions, is near impossible. However, when viewed singularly there are published studies supporting them.

These results are consistent with those of other studies by (Bailenson, Yee, et al., 2008, Brelsford, 1993, Trindade et al., 2002) and 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 greater learning. In
contrast, the findings of the current study for learning outcomes do not support the previous findings by Crosier et al. (2000). I speculate that the combination of actively engaging multiple participants’ senses while providing an alternative to the highly overused PowerPoint in military education/training (i.e. motivation) contributed to the investigational groups’ success. This would agree in part with Wickens (1992) who states that VR can be broken down into five parts a) 3D perspective, b) dynamic rendering, c) closed loop interaction, d) egocentric perspective, and e) enhanced sensory feedback. Similar to findings by Wang (2012) the VR-based instruction also allowed participants’ to be active learners instead of passive receivers of information. 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 VR-based and lecture-based multimedia instruction would allow for a greater range of learning styles. Consistent with Mikropoulos et al. (2003) immersive VLEs will continue to be a valuable educational tool. However, stakeholders must be aware of not allowing the novelty of the technology overshadow its true purpose in the classroom.

In terms of long-term retention, the results disagree with previously published findings (Brelsford, 1993, Jia et al., 2012, Kontogeorgiou et al., 2008) showing that VR-based instruction was superior to lecture-based. I venture this is a direct result of the smaller sample size and a few outlying scores. Intuitively you would think that all participants’ scores would increase from pre- to post-exam immediately following the training and then decrease from post- to long-term retention exam following a month of
no known CPC training. A possible explanation for the 33 percent of participants \( N = 9 \) with a score increase, approximately a month following first contact, could be that the participants acquired additional CPC training and/or knowledge elsewhere. Another possible link is that the participants had now become aware of CPC and began to utilize. With the long-term retention exam being online and not proctored, there was the possibility for cheating too. I speculate that the increase scoring was due in part to looking up answers. If true, this would explain the contradiction between past findings and the data showing that the control group retains the information in the long-term better than the investigational.

Analysis of exit questionnaire data provided the formation of the fourth conclusions. Note that the median age of the sample was 28 years, which would place most within the Generation Y demographic. A rising trend for the millennial generation is to readily accept new technologies and remain heavily connected throughout their daily lives, including education. Google (2012b) reports that 90 percent of all media interactions are screen based and Google (2012a) shows just how hyper-connected teens and twenty-somethings are, 92 percent engaging with at least two devices simultaneously. Finally, gaming is no longer only for kids and young adults. Even if the game play built into the immersive VLEs were easy and/or childish it excited the majority of the sample when mentioned.

The most common complaint with the VR system was HMD comfort and Kinect tracking accuracy. To remedy the issues while continuing to provide a low-cost system solution the HMD needs to be upgraded to the Oculus Rift and the Kinect to the Kinect for Windows v2.
The most cited affordances of VR are increased interaction, immersion, engagement, entertainment, and motivation. These characteristics provide a means to active learning. The learner is no longer strictly a listening device but now encouraged and often forced to participate and interact with the training material. The trainee will display a sense of motivation to learn often unobtainable with lecture-based instruction.

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. Statements by Headquarters Department of the Army (2002) and Minogue et al. (2006) agree:

Virtual and constructive training cannot replace all live training. They can, however, supplement, enhance, and complement live training to sustain unit proficiency within the Band of Excellence. (p. 4~15)

That is to say, if new and innovative technologies (such as VR and haptic devices) are more engaging and appealing to students and if in turn these learners are motivated to interact with these learning environments longer than with traditional print materials then this in itself may justify the use of and deeper investigation of these new technologies. (p. 304)
Future Work

To successfully combat corrosion, individuals across all disciplines must be educated on what corrosion is and just how dangerous it can be if left untreated. This research study has shown that immersive VR works on soldiers, but future studies will need to take place with other demographics before further generalization. Replicating the study with upgrades to the HMD and controller, could also possibly produce different results. Staying with the problem of corrosion, the VR system and VEs could be enhanced with other technologies, such as haptic or gesture/motion control devices. This would open the possibilities of other training topics, which are more hands on, such as general corrosion repair procedures/techniques (e.g. washing, cleaning, painting, coating, removal of corrosion, or applying preventative compound treatments).

Ultimately, the CPO would like to increase the complexity of the system by incorporating scalable (e.g. full-size) 3D models of various aviation assets (i.e. rotorcraft, missile systems, etc.). The trainee would have the capability to observe and explore the models while being tracked in real time. This scenario would provide the trainee with a highly realistic training environment and increase the interactivity between virtual content and trainee. However, it also significantly increases complexity and cost. The position tracking system (i.e. Kinect) would most likely need to be upgraded to a full-scale optical system and the trainee would need to be untethered (i.e. wireless VR system). The hardware and software to make a training environment as described above is possible. It would be costly and not easily scalable and/or portable. However, once developed and operational it could possibly decrease training costs as the aviation assets are now virtual, available on demand, and easily modified.
The AMCOM CPO’s CPC training course is a means for maintainers of aviation equipment to refresh their knowledge of basic CPC theories, principles, and practices.

The issue is that when a soldier signs up for the course he or she must attend the full length of the course. What if the soldier already has exemplary skills in identify corrosion but needs to only learn about the newest regulations? Could you not create a VR scenario that acknowledges just-in-time training? This system could also allow a user to predefine their learning objectives or a system that accesses the users’ prior knowledge. The pre-assessment could even take place within the immersive VLE and scoring would automatically adjust training length and/or material.

The original end goal for the VR system created during this research study was to complement and/or augment existing lecture-based CPC instruction that takes place at the AMCOM CPO. Next to the classroom used for the lecture-based instruction, a number of VR systems would be setup to provide the trainees with additional CPC training during their breaks and free time. It was never intended for the CPO’s instructors to be able to utilize the system when offsite. This was largely because the VR system is relatively complicated to setup and currently requires a fulltime moderator. Future work on converting each training module to an executable program file for wider distribution and ease of access should be done. An instruction manual for setting up, calibrating, and troubleshooting the system is also needed.

There are other educational/training topics other than corrosion with declarative knowledge aspects, where implementing immersive VLEs could help learning outcomes. The topics of chemistry, physics, and mathematics all have concepts, such as memorizing the periodic table, understanding atomic structure and molecular geometry, or
discovering the differences between gravitational, electric, and magnetic fields. Research studies concerned with these topics would of course introduce a much younger population to immersive VLEs and generalizing the results further. These fields also have numerous areas of study that are concerned with natural occurring phenomenons invisible to the human eye. Another affordance often contributed to VR is the ability to display these phenomenons in 3D and at a scale that allows the learner to view them. Imagine if a user viewed a 2D image of a type of corrosion and on their command they could position themselves inside the material and see the individual elements reacting (i.e. corroding).

Research studies conducted on long-term retention after VR use continues to be an area of much need empirical research. There are very few published studies and most just do not have the sample sizes needed to provide validity. In the end, this study was just another example of just how hard it is to retain participation from the sample after initial contact.
LIST OF REFERENCES


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APPENDIX A

IRB APPROVAL FORMS
Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on January 24, 2017. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator: WEBSTER, RUSTIN
Co-Investigator(s):
Protocol Number: X120911007
Protocol Title: Corrosion prevention and control training in an immersive virtual learning environment

The IRB reviewed and approved the above named project on 10-16-12. The review was conducted in accordance with UAB's Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.
IRB Approval Date: 10-16-12
Date IRB Approval Issued: 10-16-12

Marilyn Doss, M.A.
Vice Chair of the Institutional Review Board for Human Use (IRB)

Investigators please note:

The IRB approved consent form used in the study must contain the IRB approval date and expiration date.

IRB approval is given for one year unless otherwise noted. For projects subject to annual review research activities may not continue past the one year anniversary of the IRB approval date.

Any modifications in the study methodology, protocol and/or consent form must be submitted for review and approval to the IRB prior to implementation.

Adverse Events and/or unanticipated risks to subjects or others at UAB or other participating institutions must be reported promptly to the IRB.
Form 4: IRB Approval Form
Identification and Certification of Research
Projects Involving Human Subjects

UAB's Institutional Review Boards for Human Use (IRBs) have an approved Federalwide Assurance with the Office for Human Research Protections (OHRP). The Assurance number is FWA00005960 and it expires on January 24, 2017. The UAB IRBs are also in compliance with 21 CFR Parts 50 and 56.

Principal Investigator: WEBSTER, RUSTIN
Co-investigator(s):
Protocol Number: X120911007
Protocol Title: Corrosion prevention and control training in an immersive virtual learning environment

The IRB reviewed and approved the above named project on 10-6-13. The review was conducted in accordance with UAB’s Assurance of Compliance approved by the Department of Health and Human Services. This Project will be subject to Annual continuing review as provided in that Assurance.

This project received EXPEDITED review.
IRB Approval Date: 10-6-13
Date IRB Approval Issued: 10-6-13
IRB Approval No Longer Valid On: 10-6-14

Marilyn Doss, M.A.
Vice Chair of the Institutional Review Board for Human Use (IRB)

In case of any questions please contact:

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Alabama at Birmingham
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A3 470
1720 2ND AVE S
BIRMINGHAM AL 35294-0104

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Institutional Review Board
Protocol Oversight Review Form

Date Submitted to IRB: September 11, 2012

Title of Project: Corrosion prevention and control training in an immersive virtual learning environment

Name of Principal Investigator: Rustin D Webster

Signature of Principal Investigator: [Signature]

School: University of Alabama at Birmingham
Department: Mechanical Engineering
Division: N/A

Review Process (as determined by Department Chair):
☑ Departmental Review
☐ Divisional Review (Division Director or Designate)
☐ Center or Departmental Protocol Review Committee Review
☐ Project Review Panel (PRP)—Appointed by the Department Chairman or Division Director (PRP report attached)

I have reviewed the proposed research and concluded that the following apply:
- The research is scientifically valid and is likely to answer the scientific question;
- The researcher and the study team are qualified and/or credentialed to conduct the procedures proposed;
- The researcher has identified sufficient resources in terms of experienced research personnel, facilities, and availability of medical or psychological services that may be necessary as a consequence of participation in the research to protect the research participants.

Name of Official: Dr. Bharat Soni
Title: UAB Mechanical Engineering Department Chair
(type or print)

Signature: [Signature]
Date: 9/11/12
Waiver of Informed Consent Documentation

1. IRB Protocol Title: Corrosion prevention and control training in an immersive virtual learning environment.

2. Principal Investigator: Rustin D Webster

3. Choose one of the checkboxes below, indicating why the waiver of documentation is being requested for this research, and provide protocol-specific details as requested.

☐ Confidentiality Risk—Respond to Items a–c, below.
   a. Would the only record linking the subject and the research be the consent document?  Yes ☐ No ☐
   b. Would the principal risk be the potential harm resulting from a breach in confidentiality? Yes ☐ No ☐
   c. Describe your plans to ask each subject whether he/she wants documentation linking his/her name with the research, and how each subject's wishes will govern (e.g., a document could be used for the informed consent process, subjects would be asked if they wanted a signed copy to document their consent, and those who did not would receive an unsigned copy).

☒ The research involves no greater than minimal risk and no procedures for which written consent is normally required outside the research context. Respond to Item a, below.
   a. Describe plans, if any, that you have for providing subjects with a written statement regarding the research. (Note: The IRB may require that a written statement be given to the subject.) The participants will be given an unsigned copy of the informed consent document. The availability and access to a copier or scanner to give them the a signed copy will most likely be limited if not completely unattainable due to the research study locations taking place on various U.S. Army installations.

By signing this request for waiver of informed consent documentation, I certify the information included in it.

Principal Investigator's Signature ____________________________ Date 9/11/12

UAB IRB

Date of Approval 10-11-12
Not Valid On 10-16-15
FOCUS GROUP INFORMED CONSENT DOCUMENT

TITLE OF RESEARCH: Corrosion prevention and control training in an immersive virtual learning environment

IRB PROTOCOL: X120911007

INVESTIGATOR: Rustin D Webster

SPONSOR: University of Alabama at Birmingham’s Department of Mechanical Engineering

Purpose of the Research

We are asking you to take part in a research study (i.e. focus group) to validate instruments which will be used in a formal research study. The purpose of the formal research study is to compare the routine classroom instructor-led training (i.e. lecture-based multimedia instruction) and immersive virtual learning environment (VLE) training (i.e. virtual reality-based multimedia instruction) in terms of learning and long-term retention of basic corrosion prevention and control (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 CPC training course.

Explanation of Procedures

If chosen to be a participant in part one of the focus group, in addition to the routine AMCOM Corrosion Program Office’s CPC training course, you will be asked to complete (i.e. fill out) and discuss a pre-exam, entrance and exit questionnaire, and interview with the principal investigator. This part of the focus group will enroll 5-10 participants. All information and feedback will remain confidential.

If chosen to be a participant in part two of the focus group you will be asked to complete and evaluate pre- and post- exams concerning corrosion prevention and control principles and theories for accuracy, level of difficulty, and appropriateness for the targeted formal research study participants. This part of the focus group will enroll 5-10 participants. All information and feedback will remain confidential.

Completion of either part of the focus group will take approximately 15-30 minutes. The focus group tasks are not tiring. However, you may terminate your participation at any time, for any reason. You are requested to refrain from discussing any information from the focus group with other individuals or with people who might be in the candidate pool from which other participants might be drawn.

You will be given full instructions before proceeding. If anything is unclear, be sure to ask the principal investigator questions.

Page 1 of 3
Version Date: 25 February 2013
Risks and Discomforts

There are no physical risks anticipated with this research study. There is, however, the potential risk of loss of confidentiality. Every effort will be made to keep your information confidential; however, this cannot be guaranteed. Some of the questions we will ask you as part of this focus group may make you feel uncomfortable. You may refuse to answer any of the questions and you may take a break at any time during the research study.

Benefits

You may not directly benefit from taking part in this research study. However, your participation may help better design research instrumentations for a formal research study concerning the use of an immersive VLE for corrosion prevention and control training.

Alternatives

The alternative to participating in this research study is not to participate and continue with the routine AMCOM Corrosion Program Office’s corrosion prevention and control training course.

Confidentiality

Information obtained about you for this focus group will be kept confidential to the extent allowed by law. However, research information that identifies you may be shared with the University of Alabama at Birmingham’s Department of Mechanical Engineering, University of Alabama at Birmingham’s Institutional Review Board (IRB), U.S. Army Human Research Protections Office (AHRPO), and others who are responsible for ensuring compliance with laws and regulations related to research, including the Office for Human Research Protections (OHRP). The results of the focus group may be published for scientific purposes. However, your identity will not be given out. There is no guarantee that other participants will not repeat your comments outside the focus group at some time in the future.

Voluntary Participation and Withdrawal

Whether or not you take part in this research study is your choice. There will be no penalty if you decide not to participate. You are free to withdraw from this research study at any time. Your choice to leave the research study will not affect your relationship with the University of Alabama at Birmingham, U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office, or any other U.S. Army installation. If you do decide to withdraw from this research study you will continue with the routine AMCOM Corrosion Program Office’s corrosion prevention and control training.

You may not qualify for the research study based on your answers to the entrance questionnaire.

Cost of Participation

There will be no cost to you for taking part in this research study.
Payment for Participation in Research

You will not be paid for your participation in this research study.

Questions

If you have any questions, concerns, or complaints about the research study, please contact Rustin D Webster. He will be glad to answer any of your questions. The phone number is 309-253-1512. You may also contact the University of Alabama at Birmingham’s Mechanical Engineering Department’s chairman, Dr. Bharat Soni at 253-934-8460.

If you have questions about your rights as a research participant, or concerns or complaints about the research, you may contact the Office of the IRB (OIRB) at (205) 934-3789 or 1-800-822-8816. If calling the toll-free number, press the option for “all other calls” or for an operator/attendant and ask for extension 4-3789. Regular hours for the OIRB are 8:00 a.m. to 5:00 p.m. CT, Monday through Friday. You may also call this number in the event the research staff cannot be reached or you wish to talk to someone else.

If you have questions about your rights as a research participant, or concerns or complaints about the research, you may also contact the U.S. Army Human Research Protections Office (AHRPO) at (703) 681-6365.

Legal Rights

You are not waiving any of your legal rights by signing this informed consent document.

Signatures

Your signature below indicates that you agree to participate in this research study. You will receive a copy of this unsigned document.

Name of Participant (please print)

Signature of Participant

Signature of Principal Investigator

Date

Date

Page 3 of 3
Version Date: 25 February 2013
FORMAL RESEARCH STUDY INFORMED CONSENT DOCUMENT

TITLE OF RESEARCH: Corrosion prevention and control training in an immersive virtual learning environment

IRB PROTOCOL: X120911007

INVESTIGATOR: Rustin D Webster

SPONSOR: University of Alabama at Birmingham’s Department of Mechanical Engineering

Purpose of the Research

We are asking you to take part in a research study. The purpose of this formal research study is to compare the routine classroom instructor-led training (i.e. lecture-based multimedia instruction) and immersive virtual learning environment (VLE) training (i.e. virtual reality-based multimedia instruction) in terms of learning and long-term retention of basic corrosion prevention and control (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 CPC training course.

A virtual environment can be defined as an artificial, three-dimensional graphical representation of an environment based on real-world or abstract objects and data. The VLE will be part of a system consisting of output and input devices and tracking devices. The training material will be viewed in three-dimension (3D) with depth (stereoscopic), which you the participant will interact with (e.g. travel, selection, manipulation, and system control) by body movements and input devices.

Explanation of Procedures

People who qualify to be part of this research study will be randomly placed in either the control group (routine training) or investigational group (VLE). This research study will enroll approximately 300 participants for the control group and 30 for the investigational group nationwide. Completion of the research study will take approximately 4 hours for the control group and 2-4 hours for each participant of the investigational group. All information regarding your performance will remain confidential. You are requested to refrain from discussing any information from the research study with other individuals or with people who might be in the candidate pool from which other participants might be drawn.

The control group will be asked to fill out an entrance questionnaire relating to your demographics and background. Next, you will take a closed book exam testing your knowledge of corrosion prevention and control theories and principles. After completing a portion of the routine AMCOM Corrosion Program Office’s corrosion prevention and control training course, you will take a closed book exam so that learning can be analyzed. After approximately 3 weeks you will receive an email containing a link and password to a digital exam that you will take

UAB IRB

Date of Approval 10-8-13

Not Valid On 10-5-14
without using any reference material, textbooks, or external sources so long-term retention can
be analyzed.

The randomly selected participants for the investigational group will be asked to complete three
training sessions using the virtual reality training system. The first session (usage session) will
show you how to properly wear and operate the individual components of the system. The
components of the system include a head mounted display (HMD) that you will wear while
completing the training. The second and third session (training module 1 & 2) will be on
corrosion prevention and control principles and theories.

The investigational group will be asked to fill out an entrance questionnaire relating to your
demographics and background. You will also take a closed book exam testing your knowledge of
corrosion prevention and control principles and theories. After using the immersive VLE, you
will also be asked to fill out an exit questionnaire and take part in a short interview with the
principal investigator. Finally, you will take a closed book exam so that learning can be
analyzed. After approximately 3 weeks you will receive an email containing a link and password
to a digital exam that you will take without using any reference material, textbooks, or external
sources so long-term retention can be analyzed.

You will be given full instructions before proceeding. If anything is unclear, be sure to ask the
principal investigator questions.

Risks and Discomforts

There are no anticipated risks or discomforts for participants of the control group. There is,
however, the potential risk of loss of confidentiality. Every effort will be made to keep your
information confidential; however, this cannot be guaranteed.

Participants of the investigational group will be using a commercially available head mounted
display, tracking devices, and input devices. However, you may experience some slight
discomfort during the training sessions. The head mounted display will make contact with your
head and face, specifically the back of your scalp, forehead, and nose. If you find the fit to be
uncomfortable at any time fitting adjustments can be made. Additionally, a small number of
people may experience slight eye strain, headaches, and/or motion sickness (dizziness, fatigue,
and/or nausea) while using the immersive VLE. If you experience any of these symptoms, you
will be given the opportunity to rest until the symptoms subside before continuing or you may
exit the research study completely. All light and sound intensities are well within normal ranges.
There is the potential risk of loss of confidentiality. Every effort will be made to keep your
information confidential; however, this cannot be guaranteed. No other portions of this research
study for the investigational group are anticipated to cause risk or discomfort of any type.

Participants of the investigational group will be randomly assigned, the training you receive may
prove to be less effective than the control group.

Benefits

Page 2 of 4
Version Date: 25 February 2013
You may not directly benefit from taking part in this research study. However, your participation in the research study will provide information that may be used to improve the design of virtual training environments, systems, hardware, and/or software. Your input will provide the U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office with a valuable evaluation of a real-world application using an immersive VLE for corrosion prevention and control training.

**Alternatives**

The alternative to participating in this research study is not to participate and continue with the routine AMCOM Corrosion Program Office’s corrosion prevention and control training course.

**Confidentiality**

Information obtained about you for this research study will be kept confidential to the extent allowed by law. However, research information that identifies you may be shared with the University of Alabama at Birmingham’s Department of Mechanical Engineering, University of Alabama at Birmingham’s Institutional Review Board (IRB), U.S. Army Human Research Protections Office (AHRPO), and others who are responsible for ensuring compliance with laws and regulations related to research, including the Office for Human Research Protections (OHRP). The results of the research study may be published for scientific purposes. However, your identity will not be given out.

**Voluntary Participation and Withdrawal**

Whether or not you take part in this research study is your choice. There will be no penalty if you decide not to participate. You are free to withdraw from this research study at any time. Your choice to leave the research study will not affect your relationship with the University of Alabama at Birmingham, U.S. Army Aviation and Missile Life Cycle Management Command (AMCOM) Corrosion Program Office, or any other U.S. Army installation. If you decide to withdraw from this research study, you will continue with the routine AMCOM Corrosion Program Office’s corrosion prevention and control training.

Randomly selected participants for the investigational group may be removed and placed back into the control group based on your entrance questionnaire answers. Control group participants may also be removed from the research study without your consent based on your entrance questionnaire answers.

**Cost of Participation**

There will be no cost to you for taking part in this research study.

**Payment for Participation in Research**

You will not be paid for your participation in this research study.
The University of Alabama at Birmingham has not provided any payment if you are harmed as a result of taking part in this research study. If such harm occurs, treatment will be provided. However, this treatment will not be provided free of charge.

Questions

If you have any questions, concerns, or complaints about the research study, please contact Rustin D Webster. He will be glad to answer any of your questions. The phone number is 309-253-1512. You may also contact the University of Alabama at Birmingham’s Mechanical Engineering Department’s chairman, Dr. Bharat Soni at 253-934-8460.

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If you have questions about your rights as a research participant, or concerns or complaints about the research, you may also contact the U.S. Army Human Research Protections Office (AHRO) at (703) 681-6565.

Legal Rights

You are not waiving any of your legal rights by signing this informed consent document.

Signatures

Your signature below indicates that you agree to participate in this research study. You will receive a copy of this unsigned document.

Name of Participant (please print)

Signature of Participant

Date

Participant’s Unique Identifier (please print)
- last four digits of your social security number + favorite sports team or,
- last four digits of your phone number + street you grew up on or,
- last four digits of your zip code + pets name

Signature of Principal Investigator

Date

Page 4 of 4
Version Date: 25 February 2013
Entrance Questionnaire

Please answer the following questions.

Email (please print clearly): ____________________________________________

Job title or position, if any (please print clearly): _____________________________

Gender (circle one):

- Male
- Female

Age: ______________________

Have you previously attended an AMCOM Corrosion Program Office’s corrosion prevention and control training course (circle one)?

- No
- Yes
- Unsure

Using the scale below, please indicate any current health concerns by circling the appropriate numbers.

<table>
<thead>
<tr>
<th>Health Concerns</th>
<th>No</th>
<th>Yes</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Colorblindness</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>2. Conjunctivitis (pinkeye)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3. Corneal Ulcers</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4. Corneal Infections</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>5. “Dry Eye”</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>6. Uveitis (uvea inflammation)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7. Cataracts or Glaucoma</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>8. Pregnancy</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>9. Ear Infections</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>10. Influenza (flue)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>11. Head Cold</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>12. Respiratory Ailments</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>13. “Heavy” Hangover</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>14. Amblyopia (lazy eye)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>15. Strabismus (crossed eyes)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>16. Extreme Fatigue</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>17. Emotional Stress</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>18. Digestive Problems</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>19. Significant Sleep Loss</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>20. Anxiety</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Will you be wearing prescription glasses or contact lenses during the research study (circle one)?

- No
- Glasses
- Contact Lenses

Are you left or right hand dominant (circle one)?

- Left
- Right
- Ambidextrous

Using the scale below, please rate how familiar you are with corrosion prevention and control (circle one):

<table>
<thead>
<tr>
<th>None</th>
<th>Slightly</th>
<th>Somewhat</th>
<th>Moderately</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Using the scale below, please rate how familiar you are with computers and/or smartphones (circle one):

<table>
<thead>
<tr>
<th>None</th>
<th>Slightly</th>
<th>Somewhat</th>
<th>Moderately</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Using the scale below, please rate how frequent you use computers and/or smartphones (personal and work) (circle one):

<table>
<thead>
<tr>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Using the scale below, please rate how frequent you play video games (circle one):

<table>
<thead>
<tr>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Using the scale below, please indicate your past experience with motion sickness by circling the appropriate numbers.

<table>
<thead>
<tr>
<th>Motion Sickness (dizziness, fatigue, and/or nausea)</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Always</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Traveling by car</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>2. Traveling by boat</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3. Traveling by airplane</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>4. Riding an amusement park ride</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5. Watching a 2D movie</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>6. Watching a 3D movie</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7. Playing a video game on a PC</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>8. Playing a video game on a game console</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Page 2 of 3
Version Date: 26 April 2013
Using the scale below, please rate how familiar you are with Virtual Reality (VR), Augmented Reality, and/or Virtual Environments (VE) (circle one):

<table>
<thead>
<tr>
<th>None</th>
<th>Slightly</th>
<th>Somewhat</th>
<th>Moderately</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Prior to this research study presentation have you ever heard of Virtual Reality (VR), Augmented Reality, and/or Virtual Environments (VE) (circle one)?

- No
- Yes
- Unsure

If yes, please describe it (e.g. where did you hear about it, what type of VR/VE was it, what kind of application was it being used for, etc.) (please print clearly).

____________________________________________________________

Have you ever used an immersive Virtual Reality (VR) system (e.g. head mounted display, projection-based, and/or simulator) (circle one)?

- No
- Yes
- Unsure

If yes, please describe it (e.g. what type of display was used, what kind of application, how did you interact with the system, etc.) (please print clearly).

____________________________________________________________

Do you believe you can safely stand for three 15 minute intervals while wearing a visual display on your head weighing approximately 1 lb., move body and limbs within a 25 ft² zone, and operate a single handed joystick controller simultaneously?

- No
- Yes
- Unsure
Exit Questionnaire

Please answer the following questions.

Using the different scales for each section below, please indicate your answers by circling the appropriate numbers.

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Very Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engagement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Usage Module</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Training Module 1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Training Module 2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Training as a whole</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Satisfaction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Usage Module</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Training Module 1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Training Module 2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Training as a whole</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Comfort</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Head Mounted Display (Sony® HMZ-T1™)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Tracking Device (Microsoft® Kinect®)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Controller (Zeemote® JS1)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Tactile Mat</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Ease of Use</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Usage Module</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Training Module 1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Training Module 2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Training as a whole</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Ease of Learning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Usage Module</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Training Module 1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Training Module 2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Training as a whole</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
### Content (training information)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The training information I have received was adequate for the time frame</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. The training information I have received was given in a logical fashion</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. The training information I have received is useful for my job</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. The training information I have received will make my job easier</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. The training information I have received will allow me to perform better at my job</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. The training information I have received was complicated to understand</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

### Hardware/Software (immersive virtual learning environment)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Visibility (e.g. resolution) of the display was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Tracking of the trainee (e.g. body limbs) in the virtual learning environment was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Travel (e.g. movement or navigation) in the virtual learning environment was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Selection (e.g. selecting jigsaw pieces or shooting balloons) in the virtual learning environment was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. Manipulation (e.g. movement of jigsaw pieces) in the virtual learning environment was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. System control (e.g. video controls) in the virtual learning environment was good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Using the scale below, how serious were you in completing the training modules using the immersive virtual learning environment (circle one)?

<table>
<thead>
<tr>
<th>None</th>
<th>Slightly</th>
<th>Somewhat</th>
<th>Moderately</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Would you like additional training sessions in the immersive virtual learning environment (circle one)?

- No  
- Yes  
- Unsure

Do you feel that immersive virtual learning environment based training is an efficient method of training for the topics covered? (circle one)?

- No  
- Yes  
- Unsure

Please choose your preferred learning environment for corrosion prevention and control training (circle one)?

- Classroom with live/real instructor (e.g., PowerPoint®, hands-on, etc.)
- Virtual learning environment
- Combination of both
Exit Interview

What did you like, if anything, about training in the immersive virtual learning environment?

__________________________________________________________

__________________________________________________________

What did you dislike, if anything, about training the immersive virtual learning environment?

__________________________________________________________

__________________________________________________________

What did you find frustrating, if anything, about this training style?

__________________________________________________________

__________________________________________________________

What did you find engaging, if anything, about this training style?

__________________________________________________________

__________________________________________________________

Did you get a sense of presence (a sense of being there) when in the virtual environment, and if so, do you think that affects the quality of the virtual reality training for corrosion prevention and control?

__________________________________________________________

__________________________________________________________

Do you have any other comments and/or suggestions?

__________________________________________________________

__________________________________________________________

Participant's Unique Identifier (please print):

__________________________________________________________

Page 1 of 1
Version Date: 3 January 2013
Pre-Exam

For questions 1 thru 6, please mark **ALL** the correct answers to each question.

1. Which of the following does corrosion affect?
   - [ ] Military equipment
   - [ ] Military readiness
   - [ ] Safety
   - [ ] Logistics

2. Corrosion Preventative Compounds (CPCs):
   - [ ] Should **not** be used as an additional layer of protection in corrosion prone areas
   - [ ] Designed for short term protection
   - [ ] Should be applied before any dirt, oil, and/or grease are removed
   - [ ] Provide a thin protective coating which can help displace electrolytes

3. Which factors can increase the rate of corrosion?
   - [ ] The degree (i.e. strength) of ion concentration in an electrolyte
   - [ ] The electrochemical potentials of the materials in an electrochemical cell
   - [ ] The number of freely moving electrons in the electrolyte
   - [ ] The presence of higher temperatures

4. A cathode:
   - [ ] Consumes or receives electrons through reduction (protection)
   - [ ] Is where cations migrate and diffuse towards
   - [ ] Gives off electrons through oxidation (corrosion)
   - [ ] Is where anions migrate and diffuse towards

5. Different types of corrosion:
   - [ ] Will have various appearances
   - [ ] Will require different inspection techniques
   - [ ] Will cause different failures
   - [ ] Will require different preventative and repair procedures

6. In an electrochemical cell:
   - [ ] The anode and cathode can indirectly be in contact with each other
   - [ ] The anode and cathode can be microscopically separate sites but be located on the same piece of metal
   - [ ] The anode or cathode is generally eliminated by grinding, sanding, or milling
   - [ ] The anode and cathode can be represented by the combination of an aluminum washer connected to a steel bolt

Page 1 of 4
Version Date: 8 April 2013

Participant’s Unique Identifier (please print): ____________________________
For questions 7 thru 16, please choose the ONE correct answer to each question.

7. Corrosion is best defined as:
   [ ] Electrochemical deterioration of only metal, which allows it to return to its natural state
   [ ] Process of converting metal from its natural state to metallic alloys
   [ ] Imbalance of energy between two substances that equalizes during an electrochemical reaction
   [ ] Deterioration of a substance (usually metal) or its properties due to a reaction with the environment

8. Which electrolyte will corrode metal 1000 times quicker than distilled water because of a heavy saturation of ions?
   [ ] Soda
   [ ] Salt water
   [ ] Juice
   [ ] Energy drink

9. Which is the most common electrolyte that influences corrosion?
   [ ] Soda
   [ ] Water
   [ ] Dirt
   [ ] Soap

10. Using primers, sealants, gaskets, wet fastener installation, electrical bonding, and other sealing techniques are good practices to eliminate the _____ in an electrochemical cell?
    [ ] Conductive path
    [ ] Anode
    [ ] Cathode
    [ ] Stress cracking

11. Based on the galvanic series of metals and alloys in seawater which material is most anodic?
    [ ] Zinc
    [ ] Graphite
    [ ] Magnesium
    [ ] Titanium
12. Corrosion costs for the Department of Defense are in the:

☐ Millions of dollars
☐ Thousands of
☐ Billions of dollars
☐ Trillions of dollars

13. Using protective coatings that contain corrosion inhibitors, ensuring drain holes are not clogged, use of CPCs, repairing damaged or defective paint and primer coatings, and general use of sealants are some of the methods to _______ and/or _______ the further progression of corrosion.

☐ Check; Monitor
☐ Prevent; Control
☐ Start; Stop
☐ Slow; Proliferate

14. Early detection, identification, and/or treatment of corrosion are essential to an effective corrosion control program and are accomplished by frequent corrosion of military equipment.

☐ Reviews
☐ Walkthroughs
☐ Inspections
☐ Protocols

15. All forms of corrosion, with the exception of some types of high temperature corrosion, occur through the action of an electrochemical cell containing ______ active elements.

☐ 4
☐ 3
☐ 6
☐ 5

16. _______ in the primer provide sacrificial protection to the metal substrate when coatings become cracked or damaged and provide longer protection than CPCs.

☐ Electrons
☐ Sacrificial cathodes
☐ Primer residue
☐ Corrosion inhibitors
For questions 17 thru 22, please match the corrosion type to the correct image and description below by choosing the correct letter (A-F).

17. Filiform:  □A □B □C □D □E □F
18. Intergranular (Exfoliation):  □A □B □C □D □E □F
19. Crevice:  □A □B □C □D □E □F
20. Galvanic:  □A □B □C □D □E □F
21. General Surface:  □A □B □C □D □E □F
22. Pitting:  □A □B □C □D □E □F

A. Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.
B. Occurs when the anode continues to grow into the metal. Magnesium & AL7075 are very susceptible.
C. Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.
D. Occurs when two different metals are in contact and an electrolyte is present.
E. Occurs when there is a break in a coating. Corrosion grows under coating. Coating lifts as corrosion products form.
F. Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

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Version Date: 8 April 2013

Unique Identifier (please print):
Post-Exam

For questions 1 thru 6, please mark ALL the correct answers to each question.

1. An anode:
   □ Consumes or receives electrons through reduction (protection)
   □ Is where cations migrate and diffuse towards
   □ Gives off electrons through oxidation (corrosion)
   □ Is where anions migrate and diffuse towards

2. Which factors can increase the rate of corrosion?
   □ The degree (i.e. strength) of ion concentration in an electrolyte
   □ The electrochemical potentials of the materials in an electrochemical cell
   □ The number of freely moving electrons in the electrolyte
   □ The presence of higher temperatures

3. Corrosion Preventative Compounds (CPCs):
   □ Should not be used as an additional layer of protection in corrosion prone areas
   □ Designed for short term protection
   □ Should be applied before any dirt, oil, and/or grease are removed
   □ Provide a thin protective coating which can help displace electrolytes

4. Corrosion prevention and control training is important because:
   □ Between 1980 and 2012, Army Aviation reported 11 fatalities directly attributable to corrosion
   □ Corrosion can never be completely stopped
   □ It always costs more to prevent corrosion than to repair the damage from it
   □ The military operates in environments generally not conducive to corrosion

5. Different types of corrosion:
   □ Will have various appearances
   □ Will require different inspection techniques
   □ Will cause different failures
   □ Will require different preventative and repair procedures

6. In an electrochemical cell:
   □ The anode and cathode can indirectly be in contact with each other
   □ The anode and cathode can be microscopically separate sites but be located on the same piece of metal
   □ The anode or cathode is generally eliminated by grinding, sanding, or milling
   □ The anode and cathode can be represented by the combination of an aluminum washer connected to a steel bolt

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Version Date: 8 April 2013

Participant's Unique Identifier (please print):
For questions 7 thru 16, please choose the ONE correct answer to each question.

7. Which electrolyte has the highest degree of ion concentration?
   - Normal household cleaning solution
   - Distilled water
   - Salt spray
   - Drinks containing high amounts of sugar

8. Using protective coatings that contain corrosion inhibitors, ensuring drain holes are not clogged, use of CPCS, repairing damaged or defective paint and primer coatings, and general use of sealants are some of the methods to _______ and/or _______ the further progression of corrosion.
   - Check; Monitor
   - Prevent; Control
   - Start; Stop
   - Slow; Proliferate

9. All forms of corrosion, with the exception of some types of high temperature corrosion, occur through the action of an electrochemical cell containing ______ active elements.
   - 4
   - 3
   - 6
   - 5

10. Based on the galvanic series of metals and alloys in seawater which material is most anodic?
    - Zinc
    - Graphite
    - Magnesium
    - Titanium

11. Which is the most common electrolyte that influences corrosion?
    - Soda
    - Water
    - Dirt
    - Soap
12. Using simple forms of ______ can reduce corrosion rates by more than a factor of 10 by providing protection against environmental conditions such as rainfall and chlorides.

☐ Resistance
☐ Defense
☐ Shielding
☐ Sheltering

13. Military equipment should be ______, ______, and ______ to protect against corrosion.

☐ Light; Fast; Strong
☐ Heavy; Slow; Weak
☐ Cleaned; Inspected; Preserved
☐ Undamaged; Unwarranted; Unused

14. Corrosion is best defined as:

☐ Electrochemical deterioration of only metal, which allows it to return to its natural state
☐ Process of converting metal from its natural state to metallic alloys
☐ Imbalance of energy between two substances that equalizes during an electrochemical reaction
☐ Deterioration of a substance (usually a metal) or its properties due to a reaction with the environment

15. Early detection, identification, and/or treatment of corrosion are essential to an effective corrosion control program and are accomplished by frequent corrosion of military equipment.

☐ Reviews
☐ Walkthroughs
☐ Inspections
☐ Protocols

16. Corrosion costs for the Dept. of Defense are in the:

☐ Millions of dollars
☐ Thousands of
☐ Billions of dollars
☐ Trillions of dollars
For questions 17 thru 22, please match the corrosion type to the correct image and description below by choosing the correct letter (A-F).

17. Pitting:  
   □ A □ B □ C □ D □ E □ F

18. General Surface:  
   □ A □ B □ C □ D □ E □ F

19. Galvanic:  
   □ A □ B □ C □ D □ E □ F

20. Crevice:  
   □ A □ B □ C □ D □ E □ F

21. Intergranular (Exfoliation):  
   □ A □ B □ C □ D □ E □ F

22. Filiform:  
   □ A □ B □ C □ D □ E □ F

A. Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.

B. Occurs when the anode continues to grow into the metal. Magnesium & AL7075 are very susceptible.

C. Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.

D. Occurs when two different metals are in contact and an electrolyte is present.

E. Occurs when there is a break in a coating. Corrosion grows under coating. Coating lifts as corrosion products form.

F. Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

Unique Identifier (please print): ____________________________
Screen shots of the online long-term retention exam.

Screen 1

Screen 2
Screen 9

Screen 10

Screen 11

179
Q8. Using protective coatings that contain corrosion inhibitors, ensuring drain holes are not clogged, use of CPC's, repairing damaged or defective paint and primer coatings, and general use of sealants are some of the methods to and/or the further progression of corrosion.

Screen 12

Q9. All forms of corrosion, with the exception of some types of high temperature corrosion, occur through the action of an electrochemical cell containing active elements.

Screen 13

Q10. Based on the galvanic series of metals and alloys in seawater which material is most anodic?

Screen 14
For questions 17 thru 22, please match the corrosion type to the correct image and description by choosing the ONE correct answer.
G17. Pitting Corrosion:

- Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.

- Occurs when two different metals are in contact and an electrolyte is present.

- Occurs when the anode continues to grow into the metal. Magnesium & Al1070H are very susceptible.

- Occurs when there is a break in a coating. Corrosion proves under coating. Coating lifts as corrosion products form.

- Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.

- Occurs when an electrolyte enters a gap between metals. Corrosion is generally not nasty.
Q16. General Surface Corrosion:

- Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.

- Occurs when the anode continues to grow into the metal. Magnesium & AL7075 are very susceptible.

- Occurs when corrosion products expand and metal layers separate.

- Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

Source: General Surface Corrosion

Screen 23
Q19. Galvanic Corrosion:

1. Occurs when a bare metal surface is exposed to an electrolyte. Flats of the surface become anodes and cathodes.

2. Occurs when two different metals are in contact and an electrolyte is present.

3. Occurs when the anode continues to grow into the metal. Magnesium & Al are very susceptible.

4. Occurs when there is a break in a coating. Corrosion grows under coating. Coating life as corrosion products form.

5. Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.

6. Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

Screen 24
Q29. Crevice Corrosion:

- Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.
- Occurs when two different metals are in contact and an electrolyte is present.
- Occurs when the anode continues to grow into the metal. Magnesium & Al7075 are very susceptible.
- Occurs when there is a break in a coating. Corrosion proceeds under coating. Coating lifts as corrosion products form.
- Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.
- Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

Screen 25
Q21. Integranular (Exfoliation) Corrosion

- Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.
- Occurs when two different metals are in contact and an electrolyte is present.
- Occurs when the anode continues to grow into the metal. Magnesium & AlTi6 are very susceptible.
- Occurs when a break in a coating. Corrosion grows under coating, coating lifts as corrosion products form.
- Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.
- Occurs when an electrolyte enters a gap between metals. Corrosion is generally not easily seen.

**Screen 26:**
Q22. Filiform Corrosion:

- Occurs when a bare metal surface is exposed to an electrolyte. Parts of the surface become anodes and cathodes.

- Occurs when two different metals are in contact and an electrolyte is present.

- Occurs when the anode continues to grow into the metal. Magnesium & Al7075 are very susceptible.

- Occurs when there is a break in a coating. Corrosion groves under coating. Coating lifts as corrosion products form.

- Occurs when corrosion attacks grain boundaries. Corrosion products expand and metal layers separate.

- Occurs when an electrolyte enters a gap between materials. Corrosion is generally not easily seen.
STOP

This is the end of the exam. You may go back and review any of the questions and/or your answers at this time. Once you click the next button (right-arrow below) your exam will be scored and inaccessible again.

Please proceed when ready.