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The Effectiveness of an Augmented Reality Learning Paradigm

Brian Valimont

Embry-Riddle Aeronautical University - Daytona Beach

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THE EFFECTIVENESS OF AN AUGMENTED REALITY LEARNING PARADIGM

By

R. BRIAN VALIMONT
B.S., Embry-Riddle Aeronautical University, 2000

A Thesis Submitted to the Department of Human Factors & Systems in Partial Fulfillment of the Requirements for the Degree of Master of Science in Human Factors & Systems

Embry-Riddle Aeronautical University
Daytona Beach, Florida
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Brian Valimont

This thesis was prepared under the direction of the candidate's thesis committee chair, Dennis A. Vincenzi, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors and Systems.

THESIS COMMITTEE:

Dennis A. Vincenzi, Ph.D., Chair

Steven Hall, Ph.D., Member

Sathya N. Ganganadharan, Ph.D., Member

Anthony Majoros, Ph.D., Member

Shawn M. Detz
MS HFS Program Coordinator

Frances J. Scheer
Department Chair, Human Factors & Systems

Associate Dean of Academics
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ABSTRACT

For decades the learning and training community has searched for a means that will incorporate the ever-growing body of research into everyday practice. While simulation and virtual reality dominate the community, the lack of real world cues in some systems and expense of others has imposed many limitations on these methods. Augmented reality (AR) incorporates computer-generated images overlaid onto real world objects. Although this technology seems to present distinct advantages over present mediums, it has yet to be determined if AR is effective for intentions of knowledge acquisition. The purpose of this study is to determine if augmented reality is a viable medium through which knowledge acquisition can occur efficiently and effectively.
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INTRODUCTION

Human learning and training is one of the most important topics facing society. The education of our fellow man is an enormous undertaking, both in terms of effort and finances, but one that is paramount to the success of the individual, businesses and the country as a whole. In 1998, the United States, alone, spent over 3.5 billion dollars on training and education. Aviation companies, such as Boeing and Delta Airlines, spend millions of dollars and countless man-hours educating new employees while simultaneously retraining current employees to maintain peak performance.

Unfortunately, even though learning is of such a grave concern, the state of the training and learning literature has been described as mediocre, but improving. John Campbell (1971) stated, “by and large, the training and development literature is voluminous, non-empirical, non-theoretical, poorly written, and dull.” Goldstein (1978) reemphasized his point, stating that the field of training and learning appears “to be dominated by a fads approach.”

However, by the 1980’s researchers were more optimistic about the quality of research being conducted, but identified a new problem in the education and training community, the separation of researcher and practitioner (Wexley, 1984; Latham, 1988). The research and theory was not being passed on and transitioned into practice (Cannon-Bowers, Tannenbaum, Salas, & Converse, 1991). The problem seems to stem from the two sides existing separately, with different concerns and objectives. This is regrettable,
as the field can not achieve its full potential without the theory, equipment, and applied techniques coming together.

Many organizations are using technology such as computer-based training and virtual reality (VR) to improve training and education practices, but in the past couple of years a new form of virtual reality called augmented reality has demonstrated great potential in many areas. Augmented reality (AR) is accomplished by overlaying computer graphics and text in the real world (Azuma, 1997). This new virtual environment is believed to incorporate the enhancement of learning and training that virtual reality has been shown to provide, without the debilitating effects of sickness associated with VR.
STATEMENT OF THE PROBLEM

Until now, augmented reality research has been concerned with the technological and applications issues of building an effective system. Only speculation has been applied to research involving human cognition and its interaction with AR. This study intends to examine how effective AR is as a learning paradigm and compare it against present learning paradigms, such as video-based instruction, interactive video-based instruction, and print instruction.
LITERATURE REVIEW

Augmented reality (AR) is an emerging technology, and because of this, little research has been accomplished incorporating AR. However, an extensive knowledge base has been established utilizing virtual reality, a sister technology of AR. More specifically, research concerning virtual reality’s enhancement of learning and training has been under way for over a decade now.

Virtual Reality

Virtual reality (VR) is a user-centered perspective, being situated in a synthetic environment, instead of viewing it (Wann & MonWilliam, 1996). It involves the user becoming an active participant in the virtual environment, interfacing with displays for which human sensation and perception is necessary for effective use (Moffat, Hampson, & Hatzipantelis, 1998).

Past research has focused on forms of computer-based training, such as virtual reality, while exploring methods to implement enhanced training systems while reducing the overall costs involved. Virtual reality has been found to provide several advantages in the learning and training arena. However, it has also proved to impose some debilitating effects on VR users.

When compared to such traditional modes of learning and training as text-based instruction, classroom lecture, and hands-on experience, the highly interactive training of virtual reality produces the tangible advantages of reduced time and cost investments.
(Fletcher, 1996; Stone, 2001). In addition to reduced time and money, virtual environments have the capability to enhance the learner’s experiences inside the environment, which aids in “elaborating the structures and processes that encode and retain these experiences facilitating knowledge acquisition” (Mikropoulos, 2001). It has been proposed that these benefits may be the direct result of the learner’s ability to customize their training through the freedom to explore and interact with anything in the environment. These freedoms that VR offers enhance intrinsic motivation, thereby, improving information encoding, retention, and later performance (Filipczak, 1996; Brown, 2001; Stone, 2001). In essence, the virtual reality training environment allows each learner to concentrate the most time and practice on the areas that are, individually, most problematic. This is perhaps the virtual environment’s greatest strength, individualizing learning and training to allow for greater time on task and practice in areas giving the learner trouble (Brown, 2001; Fisher & Ford, 1998; Kanfer & Ackerman, 1989; Stone, 2001).

More empirical support for enhanced learning and training through virtual reality comes from the neuroscience community. Neuroscience researchers have found that eye movement and EEG signals show individuals are more attentive in computer environments. Strikingly, the brain operates in a different way when it gets signals from a synthetic environment (Mikropoulos, 2001). “Everything becomes more important within the virtual environment” (Peterson, Wells, Furness, & Hunt, 1998). Experimental results concur with this theory (Bayliss & Ballard, 1998; Aguiire & D’Esposito, 1997; Maguire, Frith, Burgess, Donnett, & O’Keefe, 1998).
Mikropoulos (2001) found that brain activity showed a significant difference between participants performing a task in the real world and their counterpart in a virtual environment. Comparison of alpha and beta waves indicated a higher degree of visual attention, perception, and judgment, as well as greater response to cognitive stimulation. Theta brain waves were also compared between the two groups. Theta activity was found to be higher for those participants performing the real-world task indicating the participants performing in the virtual environment placed less mental effort on their task.

Those conducting basic research are not the only ones interested in the capabilities of virtual reality. Applications of virtual reality training are already underway in business and industry. In a study conducted by Adams (1996) (as cited in Stone, 2001), Motorola compared trainee performance on their pager robotic assembly line. They found that trainees who’d been exposed to a virtual assembly line learned faster and made fewer errors than those trainees using real off-line training equipment. Similar results were found at Ford’s Vulcan Forge facilities. Although the subject pool was small, the employees trained using virtual reality were 20% more efficient than the trainees who’d been exposed to the conventional training techniques incorporating an off-line pneumatic hammer (UK VR Forum, 1999). NASA’s Johnson Space Center conducted studies on virtual reality training of extra-vehicular activity (EVA) and payload handling. They found that trainees could complete component training in a fraction of the time required by conventional techniques (Kennedy & Saito, 1994). Lastly, the U.S. Navy experimented with virtual reality training for naval firefighters. A measurable improvement in firefighting techniques and onboard ship-navigation was seen by the firefighters that used VR over the firefighters that did not use VR (Stone, 2001).
Virtual reality is building quite a well-recognized track record for learning and training, however major flaws in the system have been exposed in the research studies.

Disadvantages of Virtual Reality

Virtual reality appears to be superior with respect to knowledge acquisition, however adverse physiological consequences associated with VR have also been documented (Regan & Ramsey, 1996; Wann & Mon-Williams, 1997; Cutmore, Hine, Maberly, Langford, & Hawgood, 2000). Virtual reality produces disorientation, headaches, nausea, and other symptoms associated with motion sickness (Cutmore et al., 2000; Kennedy & Stanney, 1997). These symptoms, termed cybersickness, are similar to simulator sickness with more severe symptoms, greater susceptibility, and greater longevity. Kennedy, Lanham, Massey, Drexler, & Lilienthal (1995) found that 60% - 70% of pilots reported symptoms of simulator sickness, while 90% - 95% of virtual reality users were affected by symptoms. In addition, VR users also reported that symptoms did not disappear a short while afterward, as they generally do in the case of simulator use, but rather lingered on after cessation of the virtual reality exposure.

The prolonged effects of cybersickness are not limited to nausea, but rather include maladaptations to subsequent normal environments (Regan & Price, 1994). Such maladaptations include:

- Changes in accommodation and vergence (Lampton et al., 1994; Rushton, Mon-Williams, & Wann, 1994)
- Transfer of inappropriate sensory-motor compensations (Durlach & Mavor, 1995; Kalawsky, 1993)
- Reduction of complex psychomotor flexibility (Lampton et al., 1994; Rushton et al., 1994)
- Reduced motor control (Baltzley, Kennedy, Berbaum, Lilienthal, & Gower, 1989).

It seems that virtual reality learners adapt their proprioceptive system and visuo-motor coordination to the virtual environment. Upon reentering a normal environment, individuals find that information on felt limb position and the visuo-motor coordination is miscalibrated. These effects, which have been reported to last for several hours, cause the individual to have to readapt, which severely inhibits their subsequent real-world performance (Biocca & Rolland, 1998; Rolland, Biocca, Barlow, & Kancherla, 1995; Stanney & Hash, 1998; Ungs, 1987; Crosby & Kennedy, 1982).

In an experiment designed to test training in virtual reality on a maintenance task (repair of an aircraft fuel valve), Barnett, Helbing, Hancock, Heininger, & Perrin (2000) found that virtual reality contained limitations to a task involving a high amount of manual manipulations. The trainees in the immersive virtual reality training complained of poor depth perception, size distortion, and difficulties with interfaces, such as manipulation of tools and components. The study remarks, “they were more focused on interfacing with virtual reality than with learning the task” (Barnett et al., 2000). It seems that virtual reality has some major obstacles in the way of sensory limitations to overcome before the full potential of positive transfer of knowledge and training can be realized (Kenyon & Afenya, 1995; Rose et al., 2000). Fortunately, a new form of virtual
environment, called augmented reality (AR) is gaining attention. Though still in its developmental infancy, AR promises to incorporate the advantages of virtual reality while compensating for VR’s inhibitions.

Augmented Reality

Augmented reality is the synthesis of computer images in the real world (Zachary, Ryder, Hicinbotham, & Bracken, 1997). A simpler definition usually identifies AR by three characteristics:

1) AR combines real world environments with computer images
2) AR is interactive in real time
3) AR is registered in three dimensions (Azuma, 1997).

The potential advantages of such a system seem almost limitless. It could create learning and training environments without major modifications to operational equipment, the use and maintenance of off-line training equipment, or without constructing and operating expensive simulator facilities. Training systems as cost efficient as augmented reality are, of course, much concern to any practitioner in industry, government, and especially military, who boast some of the most expensive and complicated systems in the world (O’Shea, Cook, & Young, 1999; Stedmon & Stone, 2001).
Augmented reality also bears another important claim over other training approaches. Unlike virtual reality, AR uses the real world as the backdrop, or environment in which to set its computer images. Using the real world provides both orientation cues which suppresses cybersickness, and also eliminates the miscalibration of visuo-motor coordination that other virtual environments often produce.

Presently, many organizations are exploring the advantages that applications of augmented reality have to offer. Literature reviews indicate state of the art research being done at the following organizations:

- University of North Carolina (develop and operate a system that allows a physician to see directly inside a patient, using AR)
- Columbia University (developing a prototype system that uses a see-through head-mounted display to explain simple end-user maintenance)
- Rochester Institute of Technology (development of a testbed augmented reality system that addresses spaceframe construction)
- Boeing (development of a system for assembly procedures)
- Siemens (development of systems for control of complex systems and processes)
- Naval Research Lab (develop and operate a battlefield information transfer system)
- University of Washington (develop an augmented reality authoring program)

These projects have furthered understanding of augmented reality, but this understanding has been limited to technological and applications studies. Human factors
and cognitive issues have yet to receive any substantial amount of research attention (Stedmon, Hill, Kalawsky, & Cook, 1999; Stone, 2001).

There are several issues that must be addressed in order to construct the most efficient and effective learning and training methods utilizing the augmented reality system. This study intents to review pertinent issues of elaboration, recall, and transfer of knowledge and training in the past literature, while studying the effectiveness of knowledge acquisition in an AR environment as compared to traditional methods of instruction.

*Elaboration & Recall*

The way in which information is encoded and retained determines both how easily it will be to retrieve the information in the future, and what cues can be used to aid this retrieval. Elaboration, the process by which one expands upon new information creating multiple associations between the incoming information from different sensory inputs, and past information already held in long-term memory, has been shown to greatly improve the encoding and retention for such new information (Fisher & Craik, 1980; Fisher, 1981). Though yet untested, researchers have theorized that augmented reality learning environments may have great potential as a facilitator of retention of learning to be later retrieved for real world tasks and environments (Valimont, Majoros, Vincenzi, & Gangadharan, 2002). AR interfaces many more modalities of human senses than present learning paradigms. By complementing human associative information processing, and aiding information integration through multi-modal sensory elaboration
by utilizing visuospatial, verbal, proprioceptive, and tactile memory while the learner is performing the knowledge acquisition tasks, AR is creating increasing amounts of elaboration on the subject material (Bjork & Bjork, 1996; Neumann & Majoros, 1998; Majoros, Vincenzi, Gangadharan, & Jackson, 2002; Valimont et al., 2002). In other words, the increased number of memory channels over present forms of instruction allows for a greater chance of the information to be encoded properly and retained in long-term memory. The proper encoding of information greatly affects whether the information will be effectively and efficiently retrieved when it is needed in the real environment (Bjork & Bjork, 1996).

In addition to incorporating multiple memory channels, AR learning is aided by two other distinct advantages. These advantages stem from using the real world environment as the learning environment. Research has shown that retrieval and recall of learned information is most effective when the similarities between the learning environment and the task environment are maximized (Tulving & Osler, 1968; Tulving & Thomson, 1973; Murdock, 1989; Bjork & Bjork, 1996). The augmented reality environment, by overlaying the annotations and graphics on the real world, optimizes similarity effectiveness by using the identical environment for acquiring knowledge and applying that knowledge, thus, promoting retention of learned information and successful retrieval of learned information during real world tasks.

The second advantage is that AR incorporates visuo-spatial ability, more commonly known as spatial cognition. Spatial cognition is associated with the representations of spatial information, such as location, in memory. The use of this type of information has been found to be an extremely powerful form of elaboration for setting
up associations in memory, not to mention that spatial information is automatically processed when visual scenes are encoded into long-term memory (Lovelace & Southall, 1983; Majoros et al., 2002; Pezdek & Evans, 1979).

Therefore, when knowledge acquisition takes place in an augmented reality system, most, if not all, information will be encoded with an associated spatial cue obtained due to AR’s use of the real-world as the learning environment. These spatial cues are highly effective mnemonic devices (Bower, 1972; Rawles, 1978; Yates, 1966). This has been supported by research that has shown that knowledge of spatial location, or cuing of spatial location dramatically improves the recall of semantic content (Pezdek & Evans, 1979).

Transfer of Knowledge and Training

The identical task and learning environments that AR uses lead to another distinct advantage, transfer of knowledge and training. Transfer of training refers to how well learned skills and information can be applied to a different situation, in AR’s case, real-world tasks (Briggs, 1969; Baldwin & Ford, 1988; Lintern, 1991). For decades, the training community has investigated why some training carries over well into task performance while other training does not. This research continually draws the same conclusion; maximizing similarity between the training, the training environment, and the task, and task environment, allows for the most efficient transfer of knowledge and training (Holding, 1976; Cyrus, 1978; Comstock, 1984). Augmented reality, by utilizing basically the same environment, has therefore brought similarity to its maximum
potential, for both training and task performance. AR is the technology that will provide the most effective benefits of training transfer and long-term information retention.
STATEMENT OF HYPOTHESIS

Four groups will be set up, a video instructional group (Observe group), an interactive, video instructional group (Interact group), an augmented reality instructional group (Select group), and a print-based instructional group (Print group), each utilizing a different media for information presentation, but all presenting the same pictorial views and information. The Observe, Interact, and Print groups represent the most common forms of media used in instructional presentations today. These groups will be used to examine how effective augmented reality, in the Select group, is at presenting information for purposes of learning when compared to presently employed methods.

Past research in the areas of elaboration, recall, spatial ability, and learning suggest that a technology, such as augmented reality, would greatly facilitate the acquisition of knowledge in the learner. The augmented reality system used by the Select group provides more sensory interfaces such as visual, spatial, verbal, tactile, and proprioceptive, than the other groups whom utilize only one or two interfaces at most. This increase in interfaces creates more memory traces and elaboration cues which will assist in acquisition, retention, and recall of knowledge.

Hypothesis

It is hypothesized that the instructional session will improve the amount of knowledge acquired concerning the work-piece as reflected on two recall tests, and that this improvement will differ across the four mediums of information presentation.
Prediction 1. The Select group will achieve significantly higher test scores during a post-recall test condition than the Observe, Interact, and Print groups following the experience of an eight-minute session of information presentation concerning the work piece.

Prediction 2. The Select group will achieve significantly higher test scores than the Observe, Interact, and Print groups during a post-recall test condition administered one week after the eight-minute work piece instructional session.
METHODS

Participants

Participants were taken from the undergraduate population at Embry-Riddle Aeronautical University. However, students that possess a superior knowledge of an aircraft oil pump, such as those students in the Aviation Maintenance Technology program, were excluded from the study.

Apparatus

The principle apparatus used for the treatment conditions consisted of a Silicon Graphics O2 Desktop CPU with operating system IRIX v 6.5, and a Toshiba Color Stream color television model number 27A41. The television had one S-Video Input, two Video In, and one Video Out connections. A JVC Super VHS player/recorder with one S-Video In and one S-Video out connection along with one audio/video in and out connections was used. The video media device that was used was a Sony color video camera (Model: CCX-Z11) that fed the video-base to the CPU to display the images. A manually manipulated turntable was used to rotate and display the work-piece. The software that was used to author the augmented reality scenes was ARToolKit v. 2.431 from the University of Washington.
Design

The experimental design was a 4 x (2 x 24) mixed measures design. There was one between-subjects independent variable, the mode of information presentation. This variable was broken up into four factors, video-based presentation (Observe group), video-based interactive presentation (Interact group), augmented reality presentation (Select group), and text-based presentation (Print group). The second independent variable was a within-subjects variable, length of time between instructional session and recall test. There were two levels of this variable, immediate post-instructional recall test, and a one-week post-instructional recall test. There was one dependent variable, amount of information correctly recalled, measured by the percentage score of each of the two recall tests.

Procedures

The participants were brought in for the first session in groups no larger than three. They were given a brief summary of the purpose, procedures, and alternatives to the experiment, along with a consent form to fill out. After the consent form, participants were tested to determine his or her visual acuity, and spatial ability. The first screening test was one of visual acuity incorporating a self-screening vision tester used to test a participant’s eyesight at reading distance, approximately 18-24 inches. The Brief Visuo-Spatial Memory Test – Revised was then administered, which tested spatial ability. As mentioned in the literature review, the ability to link information to locations spatially is a powerful mnemonic device. This advantageous ability is not present in all individuals, so it was tested for and statistically controlled using an analysis of covariance. During a
25 minute interim called for in the BVMT – R procedures, participants will be given a brief demographic survey. They will be given verbal tasks to complete for the remainder of the interim.

The experimental treatment began following the completion of the visuo-spatial test. Participants were randomly assigned to a treatment group, and given instructions on how to use the equipment provided to their training group. The Observe group underwent video training, so they were given instruction on the use of the particular VCR with which they were provided. The Interact group underwent video-based interactive training. They were given instruction on the use of the computer to bring up text boxes explaining the work-piece functions, as the video training ran on the computer monitor. The Select group underwent video-based augmented reality training. They were given instructions regarding how to interact with the computer to find information on the functions of the work-piece. Lastly, the Print group was given print-based learning tools. They were given instructions on the nature of the text they were reading, and the pictures with which they were provided.

The four groups then went through an eight-minute instructional session, learning about the terminology, functions, and locations of the work-piece (an aircraft oil pump) and its components. The participants were given a short three-minute bathroom break. When the participants returned they were given a recall test to measure how much knowledge they acquired from the instructional session. This test was scored on a zero through one hundred percent scale, with one hundred percent being a perfect score, much like the scale found in academics.
Following the post-test a short interview was conducted to debrief the participants and record their opinions on the instructional mode they experienced. This concluded session one. The average duration of session one was 50 minutes.

The last session, session two, was conducted exactly one week later. Participants were emailed the same post-instructional recall test as in session one to measure how much information the participant has retained after one week without any rehearsal. Participants emailed their answers back to the experimenter. The test was also scored on the same percentage scale as the test taken immediately after the instructional session. This concluded session two, and the experimental testing.

Data Collection

Data was collected from the two tests, the immediate post-instructional recall test and the long-term retention recall test, measuring knowledge acquisition, retention, and retrieval during the course of the experiment. Both tests were scored on the same zero through one hundred percent scale, with one hundred percent being a perfect score, much like the scale found in academics. An analysis of covariance on the two independent variables, while controlling the variable of visuo-spatial ability, was used to determine which instructional paradigm was most effective on human learning and recall. When significant differences were found through the ANCOVA process, further analysis was performed utilizing pairwise comparisons and a Bonferroni correction.
RESULTS

The results of the visuo-spatial testing did not yield any significant correlations between a participant’s visuo-spatial ability and their performance during the experimental recall tests. Therefore, group means were statistically compared using a 4x(2x24) mixed factors ANOVA instead of the planned ANCOVA method. The data were analyzed to determine the statistical significance of observed group mean differences. As can be seen in Table 1 & 2, the augmented reality group achieved the highest test scores on both the immediate post-instructional recall test and the long-term post-instructional recall test, followed by the video group, the interactive video group, and the print group, respectively.

Table 1

<table>
<thead>
<tr>
<th>Instructional Mode</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Group (Augmented Reality)</td>
<td>88.9</td>
<td>9.8</td>
<td>24</td>
</tr>
<tr>
<td>Observe Group (Video)</td>
<td>80.3</td>
<td>15.5</td>
<td>24</td>
</tr>
<tr>
<td>Interact Group (Interactive Video)</td>
<td>77.5</td>
<td>11.1</td>
<td>24</td>
</tr>
<tr>
<td>Print Group (Text &amp; Photos)</td>
<td>75.8</td>
<td>18.0</td>
<td>24</td>
</tr>
</tbody>
</table>
Table 2

Mean Scores for Long-Term Recall Test

<table>
<thead>
<tr>
<th>Instructional Mode</th>
<th>Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Group (Augmented Reality)</td>
<td>81.1</td>
<td>12.8</td>
<td>24</td>
</tr>
<tr>
<td>Observe Group (Video)</td>
<td>66.9</td>
<td>20.3</td>
<td>24</td>
</tr>
<tr>
<td>Interact Group (Interactive Video)</td>
<td>68.1</td>
<td>12.9</td>
<td>24</td>
</tr>
<tr>
<td>Print Group (Text &amp; Photos)</td>
<td>67.8</td>
<td>21.4</td>
<td>24</td>
</tr>
</tbody>
</table>

The results of the ANOVA showed a statistically significant difference between the main effects of the between subjects variable, the instructional group means, $F(3,92) = 4.25, p = .007$, and also between the main effects for the with-in subjects variable, length of time between the instruction and recall test, $F(1,92) = 68.3, p = .000$. However, the interaction between the instructional group means and the length of time between the instruction and recall test proved to be insignificant, $F(3,60) = 1.2, ns$.

Utilizing omega squared to calculate the treatment effects of the between subjects variable, mode of presentation, and the within subjects variable, length of time, the results of .09 and .26, respectively, were obtained. These treatment effects of .09 and .26 indicate that nine percent of the variation in the recall test scores between the four groups was accounted for by the manipulation of the mode of presentation, while 26 percent of the variation between the immediate recall test scores and the long-term recall test scores was accounted for by the manipulation of the length of time between instructional session and recall tests.
Table 3

### Mixed Factor ANOVA Source Table

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of Presentation</td>
<td>3</td>
<td>5496.6</td>
<td>1832.2</td>
<td>4.3</td>
<td>.007</td>
<td>.85</td>
</tr>
<tr>
<td>Error (S/A)</td>
<td>92</td>
<td>39623.5</td>
<td>430.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of Time</td>
<td>1</td>
<td>4472.1</td>
<td>4472.1</td>
<td>68.3</td>
<td>.000</td>
<td>1.0</td>
</tr>
<tr>
<td>Factorial Interaction</td>
<td>3</td>
<td>235.9</td>
<td>78.6</td>
<td>1.2</td>
<td>.31</td>
<td>.31</td>
</tr>
<tr>
<td>Error (BxS/A)</td>
<td>92</td>
<td>6024.1</td>
<td>65.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further pairwise comparisons utilized a Bonferroni correction, which lowered the alpha criteria to .044 for each comparison. This analysis showed that significant mean differences lie between the Select group and the Print group, p=.01, and between the Select group and the Interact Group, p=.035, within the immediate recall level. Such that the Select group mean immediate recall test score was significantly greater than both the Print and Interact groups. Significant mean differences were also found between the Select group and the Observe group, p=.034, within the long-term recall level. The mean long-term recall test score for the Select group was greater than the Observe group (See Table 4 and Figure 1 for complete results).
Table 4

Mean Differences of Mode of Presentation Pairwise Comparisons

<table>
<thead>
<tr>
<th>Length of Time</th>
<th>Mode of Presentation</th>
<th>Mean Differences</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate Recall</td>
<td>Select vs. Observe</td>
<td>8.6</td>
<td>.21</td>
</tr>
<tr>
<td></td>
<td>Select vs. Print</td>
<td>13.1</td>
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<td>Select vs. Interact</td>
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<td>Long-Term Recall</td>
<td>Select vs. Observe</td>
<td>14.2</td>
<td>.03</td>
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<td>Select vs. Print</td>
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<td>Select vs. Interact</td>
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Figure 1. Mean immediate and long-term recall test scores across all four experimental groups.
DISCUSSION

As the experiment revealed, there seemed to be no correlation between visuo-spatial memory and recall performance tested after the instructional session. This could be due to a lack of sensitivity on the part of the Brief Visuo-Spatial Memory Test – Revised. Although, a more plausible explanation would be that visuo-spatial memory, by itself, can not provide a significant enough correlation to used as a predictor of recall performance because the topic being explored, human learning and recall, is far too complex and entrenched in human differences to be predicted by one variable. To speculate, the proper predictor of recall performance may or may not include, optimal personal learning style (auditorily, visually, or hands-on) or motivation to learn in addition to other factors such as visuo-spatial memory. This fleshing out of the best predictor of human learning and recall for information acquired in an augmented reality environment would be best served if it were taken up as separate issue and a separate research project where the topic would be the center of the researcher’s attention. The investigation of such a predictor would have a two-fold advantage. First, it would give a clearer picture of the variables that most contribute to a learner’s success using augmented reality instruction. Second, the isolation of these variables would contribute to controlling and reducing the large amount of variability due to human differences in future augmented reality research, again allowing for a clearer picture of the actual experimental effects.
The variable of length of time between instruction and recall test rendered the result that participants of all groups recalled significantly more information immediately after the instructional session, then they did following a one week delay between instructional session and recall test. This should come as no surprise, as it validates that all subjects are forgetting, or failing to recall a portion of the learned material.

The results of the comparison between the four groups, though not resoundingly conclusive, do lean towards an interesting instructional advantage that augmented reality seems to have on its learners, and are favorable for an experiment concerning this still developing technology. As the data show, subjects who received instruction through augmented reality demonstrated significantly better immediate recall than those who received print instruction or interactive video instruction. Subjects in the augmented reality instructional group also scored significantly greater on the long-term recall test than the video group. However, the augmented reality group failed to show significantly better performance than the video group for immediate recall, and the print and interactive video groups for long-term recall. These seemingly insignificant mean differences of the groups may not be so insignificant in terms of training and retraining dollars, especially for long-term memory recall, that is, if the relationships prove to be consistent over subsequent experiments. Also, if the previously mentioned learning variables are isolated and the accompanying human variability is reduced, more conclusive significant results will more likely emerge in favor of augmented reality.

During the planning of this study, care was taken to design all four groups so that the information available to all groups during the instructional session was as consistent as possible. Total consistency was not achieved (ex: every possible viewing angle
afforded by the Select group was not printed into picture form for the Print group). In practical terms, each instructional technology employed in the study seems to have advantages and limitations that are inherent to that particular mode. To control all these advantages and limitations in attempts to achieve ultimate equality across the four modes would most likely destroy the effect under investigation. Therefore, ultimate equality across the four groups might not be in the our best interest, but a form of pre-qualification for the consistency of the informational content would be a good idea in future studies.

The advantages afforded the user by their respective instructional mode seem to stem from the amount of interaction that the instructional mode provides. The modes of Observe, Interact, and Print, while they do provide varying amounts of visual interaction, and in the case of Interact, simple tactile and motor interaction, this interaction does not compare to the Select mode of presentation. A major advantage was the Select group interacted directly with the workpiece being studied. Participants viewed screens that portrayed information, just as the Observe and Interact group did. However, the Select group controlled what information they viewed and when they viewed it. It may be that higher-level interactions, such as the customization of their learning experience coupled with the ability to match the augmented information directly with the workpiece in front of them, are an underlying cause for increased elaboration and hence, better recall using augmented reality; only future research will tell.

To reiterate the theories advanced in the beginning of this paper, it is believed that augmented reality affords better retention and recall by increasing elaboration of the material to be learned. This is accomplished by complementing human associative information processing through multiple associations utilizing multi-modal sensory
elaboration while the learner is performing the knowledge acquisition tasks. Furthermore, most, if not all, information to be acquired may be encoded with associated environmental and spatial cues. These are obtained due to AR’s use of the real world as the learning environment.

Though this experiment lends some support to the hypothesis, it only scratches the surface of augmented reality and human learning, raising more questions than it answers. Research is much needed to investigate the theories advanced in this study and others. Moreover, attention must be turned to studying the human differences and variabilities that are most prominent in determining the effectiveness that augmented reality will have on a learner. If research is conducted in these areas concurrently with the hardware and software research underway at various organizations and institutions, then this human-centered research should be ready at the doorstep when a commercially viable augmented reality system is developed.
FUTURE DIRECTIONS IN AUGMENTED REALITY RESEARCH

As previously mentioned, this research raises more questions than it answers, opening the doors for many more necessary studies in augmented reality and human learning. Theories have been put forth in this, and other research, concerning AR’s facilitation of elaboration and attention, but these theories must be studied in greater detail to determine what the nature of the elaboration is, and also how augmented reality holds, focuses, and directs attention. A good starting point for the study of attention would be to incorporate an eye-tracking device. The AR system is highly visual and measuring where a participant is looking would give a good idea of what material they are explicitly attending to, as well as the flow of their attention.

This study has shown that AR has an effect on the acquisition, retention, and recall of learned information, but more investigation is needed to determine what types of information are optimized by augmented reality’s computer overlays. It may well be that specific types of overlaid graphics have a greater effect on specific types of information. These relationships must be uncovered if AR systems are to be implemented with their full potential realized.

Projects that can be performed in the near future are those that incorporate a variation of this study, but aim to look into AR recall in longer periods of delay between the instructional session and the recall test. Periods of delay ranging from two weeks, to one month, to six months, would help to plot the percentage of recall for the four
conditions over a long period of time. In addition to studying AR recall over longer periods of time, it is recommended that AR recall move into more applied setting, where participants can, and are expected to actively and directly manipulate the workpiece(s) in a task-oriented environment. This research would expand AR past a purely learning paradigm and into an area of applied training.

With a solid foundation of basic research bringing about a better understanding of the nature of augmented reality and human cognition, more applied research can be directed toward specific goals. Some of these goals may include, the development of augmented reality to facilitate air traffic controller training in creating the appropriate, dynamic cognitive maps of their airspace, and the interaction of the aircraft within that airspace. Augmented reality also shows great potential in developing a just-in-time training system, where trainees perform productive work the very first time they learn a procedure. AR may, by the nature of its overlays in the real world, raise a non-experienced novice to skilled veteran the first time, every time. It could also be used to smooth over the interface between the human operator and their remote device. Presently, remote sensing and controlling experts are working diligently to solve the problems in this area.

Augmented reality may be just the tool to fit the needs of an assortment of different people, in industry, government, and the military.
REFERENCES


APPENDIX A

Consent Form
Embry-Riddle Aeronautical University
Effectiveness of an Augmented Reality Learning Paradigm
Participant Consent Form

Date: ______________________

When I sign this statement, I am giving my informed consent to the following basic considerations:

I understand clearly the procedures to be done, including any that might be experimental. The participant will complete the assigned experiment and execute all procedures set in the given program.

I understand clearly any discomforts and/or risks that might be associated with this research project. The experiment will be done in a controlled environment. The participant will be in a closed room with only the testing equipment.

I understand clearly any benefits anticipated from this research project. Each participant will receive bonus points at the completion of the experimental trials added to their class grade with permission from their instructor.

I have been informed about other suitable procedures that would be of advantage to me.

I understand that provisions have been made to protect my privacy and to maintain the confidentiality of data acquired through this research project. All participants’ results will be referenced with a digit code that will only be referenced by the experiment team and not by any outside students or professors in and outside Embry-Riddle Aeronautical University.

The experimenter, Brian Valimont (763-1461), has offered to answer my questions about the procedures. He can also be contacted for further information about this research project. The principal investigators/supervisors are Dr. Sathya N. Gangadharan (226-7005), and Dr. Dennis A. Vincenzi (226-7035).

I understand clearly that I may withdraw at any time from this research project without penalty or loss of benefits to which I am otherwise entitled.

I am not involved in any agreement for this project, whether written or oral, which includes language that clears the institution from alleged fault or guilt. I have not waived or released the institution or its representatives from liability for negligence, if any, which may arise in the conduct of the research project.

I, the person signing below, understand the above explanations. On this basis, I consent to participate voluntarily in the Effectiveness of an Augmented Reality Learning Paradigm.

________________________________________
Signature of person giving consent

________________________________________
Signature of experimenter
APPENDIX B

Demographic Survey
Embry-Riddle Aeronautical University
Effectiveness of an Augmented Reality Learning Paradigm
Demographic Survey

Please fill in the scantron sheet correctly and accurately with a No 2 pencil. For questions one and two, please write on the appropriate space at the top of the scantron sheet. Please remember the assigned number at the top right hand corner of this sheet. Please put this number on the scantron labeled Period. If selected for the experiment we will track you as this number for your own privacy. We ask for complete honesty for all questions. None of this information will be viewed to any outside students or faculty members for the survey.

1. Name:

2. Today’s date:

3. Home Phone Number:

4. Age
   A) 17 to 20 years
   B) 21 to 25
   C) 26 to 30
   D) 31 and over

5. Current year in College
   A) Freshmen
   B) Sophomore
   C) Junior
   D) Senior
   E) Senior extended

6. What is your major?
   A) Engineering
   B) Aeronautical Science
   C) Communications
   D) Human Factors
   E) Aviation Maintenance

7. Sex
   A) Male
   B) Female

8. How often do you use the computer daily?
   A) 10 to 8 hours
   B) 7 to 5 hours
   C) 4 to 2 hours
   D) 1 hour or less
9. Do you get motion sickness while looking at a fixed point, such as a computer screen?
   A) Yes
   B) No

10. Are you claustrophobic, if put in a small room?
    A) Yes
    B) No

11. Do you normally eat 3 meals daily?
    A) Yes
    B) No

12. Did you eat breakfast/ lunch (if applicable)/ dinner (if applicable) today?
    A) Yes
    B) No

13. How much did you sleep last night?
    A) Less than 4 hrs.
    B) 4 – 5 hrs.
    C) 6 – 7 hrs.
    D) 8 – 9 hrs.
    E) 10 or more hrs.

14. Are you currently taking any medication that affects your, attention and/or concentration?
    A) Yes
    B) No

15. Have you ever worked on, or studied about vane-type oil pumps?
    A) Yes
    B) No

16. Do you have an aircraft airframe and/or powerplant license?
    A) Yes
    B) No
APPENDIX C

Instructions for BVMT – R
1) **Say before slide 1 is shown:**

Turn to page T-1 in your booklet. I am about to show you a slide that has six figures on it. I want you to study the figures so that you can remember as many of them as possible. You will have just 10 seconds to study the entire display. I will present the figures right here (examiner points to screen where figures will be displayed). After I take the display away, try to draw each figure exactly as it appeared and in its correct location on the page. Are there any questions about these instructions?

2) Reread and clarify directions as much as necessary.

3) Show slide 1 for exactly 10 seconds. **Do not begin timing until subjects are scanning stimulus.**

4) **Say after 10 sec. period:**

Now draw as many of the figures as you can in their correct location on the page.

**Give them as much time as they need.**

5) **After all subjects are finished say:**

That was fine. Now I would like to see whether you can remember more of the figures if you have another chance. I will present the display again for 10 seconds. Try to remember as many of the figures as you can this time, including the ones you remembered on your last attempt. Try to draw each figure precisely and in its correct location. Are there any questions about these instructions?

6) Reread and clarify directions as much as necessary.

7) Show slide 2 for exactly 10 seconds. **Do not begin timing until subjects are scanning stimulus.**

8) **Say after 10 sec. period:**

Now draw as many of the figures as you can in their correct location on the page.

**Give them as much time as they need.**

9) **After all subjects are finished say:**

That was fine. Now I would like to see whether you can remember more of the figures if you have another chance. I will present the display again for 10 seconds. Try to remember as many of the figures as you can this time, including the ones you remembered on your last attempt. Try to draw each figure precisely and in its correct location. Are there any questions about these instructions?
10) Reread and clarify directions as much as necessary.

11) Show slide 3 for exactly 10 seconds. **Do not begin timing until subjects are scanning stimulus.**

12) **Say after 10 sec. period:**

   Now draw as many of the figures as you can in their correct location on the page, and write down the time when you are finished.

   **Give them as much time as they need.**

13) **After all subjects are finished say:**

   Try not to forget the display because I may ask you to remember the figures later.

14) Take response booklets from subjects. Pass out reading task. Have subjects engage in predominantly verbal tasks (reading task?) for 25 minutes.

15) Pass out response booklets **opened to page DR.**

16) **Say:**

   Remember the figures I showed you before? I want to see how many you can remember now. I know it sounds difficult, but try to draw as many of the figures as you can in their correct location on the page. Remember, try to draw them accurately. When you are finished write the time down on your sheet. Just do the best you can.
APPENDIX D

Instructional Sessions Instructional Scripts
I am about to show you instructions on an aircraft oil pump using an augmented reality system. You will have exactly eight minutes to learn as much as you can about the oil pump. Study the pump and the text boxes that are associated with the pump’s components. Later, you will be tested on the information you’ve studied. This is the oil pump in front of you. You can manually spin this turntable that the oil pump sits on top of like this (Spin turntable slowly). You can turn the table in any direction and look at any part of the pump in any order you prefer. However, do not spin the turntable any faster than this speed (Demonstrate proper speed again). Try to acquire as much information about the pump and its components. There are small tags on the pump showing the front and back of the pump. Remember this orientation as you study the oil pump. Are there any questions?
VIDEO (OBSERVE) GROUP INSTRUCTIONAL SCRIPT

I am about to show you a short instructional video on an aircraft oil pump. You will have exactly eight minutes to learn as much as you can about the oil pump. Study the pump and the text boxes that are associated with the pump’s components. Later, you will be tested on the information you’ve studied. This video is 3 minutes and thirty seconds long, so you have plenty of time to rewind, or fast-forward, or whatever you need to do to acquire as much information about the pump and its components. There are small tags on the pump showing the front and back of the pump. Remember this orientation as you study the oil pump. Are there any questions?
PRINT GROUP INSTRUCTIONAL SCRIPT

I am about to show you an instructional packet on an aircraft oil pump. You will have exactly eight minutes to learn as much as you can about the oil pump. Study the oil pump in the pictures and the text boxes that are associated with the pump's components. Later, you will be tested on the information you've studied. This packet is 8 pages long, so you will have plenty of time to look through the pages in the packet in whatever you choose, or whatever you need to do to acquire as much information about the pump and its components. There are small tags on the pump showing the front and back of the pump. Remember this orientation as you study the oil pump. Are there any questions?
I am about to show you a short interactive instructional video on an aircraft oil pump. You will have exactly eight minutes to learn as much as you can about the oil pump. Study the pump and the text boxes that are associated with the pump’s components. Later, you will be tested on the information you’ve studied. This video is 3 minutes and thirty seconds long, so you have plenty of time to rewind, or fast-forward, or whatever you need to do to acquire as much information about the pump and its components. To bring up the text boxes so they appear on the television screen, simply press down the left mouse button. As long as you keep the left mouse button held down the text boxes will appear. As soon as you release the left mouse button the text boxes will disappear. There are small tags on the pump showing the front and back of the pump. Remember this orientation as you study the oil pump. Are there any questions?
APPENDIX E

List of Text Annotations
1. **Pressure-Pumping Element Oil Outlet**  
   Inspect: No debris blocking the port.

2. **Pressure-Pumping Element Oil Inlet**  
   Inspect: No debris blocking the port.

3. **Scavenge Element Oil Inlet**  
   Inspect: No debris blocking the port.

4. **Scavenge Element Oil Outlet**  
   Inspect: No debris blocking the port.

5. **Center Bushing**  
   Separates scavenge element & pressure-pumping element. 
   Inspect: No sign of oil on sides of bushing. Oil must not mix between two elements.

6. **Scavenge Element Drive Spline**  
   Drives the inner pump mechanisms  
   Inspect: Every gear tooth must not be broken or cracked, otherwise entire drive spline must be replaced.

7. **Pressure-Pumping Element**  
   Four pieces of metal that look like a cross are metal pumping vanes  
   Inspect: The pumping element inside the metal casing rotates freely.

8. **Mounting Bolt Flanges**  
   Two holes at bottom & two holes at top are flanges that house engine-mounting bolts  
   Inspect: Inspect all four flanges for cracks.

9. **Adjusting Screw**

10. **Alignment Pin**  
    Keeps scavenge element, center bushing, & pressure element aligned during reassembly.

11. **Lock Screw**  
    Holds the center bushing in place.

12. **Scavenge Element**  
    Four pieces of metal that look like a cross are metal pumping vanes  
    Inspect: Pumping element inside the metal casing rotates freely.

13. **Silver Spanner Plug**  
    To access inner mechanisms, unscrew & remove using needle-nose pliers.

14. **Oil Pressure Sensor**
APPENDIX F

Post-Instructional Recall Test
&
Long-Term Retention Recall Test
1) With the front of the oil pump facing you, on which side is the oil pressure sensor?
   a. Top  
   b. Bottom  
   c. Right  
   d. Left

2) What is the largest port (inlet/outlet) on the oil pump?
   a. The pressure relief outlet  
   b. The scavenge inlet  
   c. The pressure pumping outlet  
   d. The oil pressure sensor inlet

3) Which part must not show any signs of oil on its sides?
   a. The drive spline  
   b. The oil pressure sensor  
   c. The scavenge element  
   d. The center bushing

4) How are the inner mechanisms accessed on the oil pump?
   a. The entire pump is removed from the engine  
   b. The top of the pump is unscrewed and removed  
   c. The silver spanner plug is unscrewed and removed  
   d. The pressure pumping outlet is unscrewed and removed

5) What part keeps all inner components centered when the pump is reassembled?
   a. The aligning pin  
   b. The center bushing  
   c. The lock screw  
   d. The silver spanner plug

6) Where is the scavenge element inlet located on the pump?
   a. The side with the part number data plate facing upward  
   b. The back of the oil pump  
   c. The front of the oil pump with the spanner plug  
   d. The side next to the pressure pumping outlet

7) How many ports must be checked for blockages?
   a. 1  
   b. 2  
   c. 3  
   d. 4
8) Which part separates the scavenge element from the pressure pumping element?
   a. The lock screw
   b. The drive spline
   c. The silver spanner plug
   d. The center bushing

9) The lock screw holds which component in place?
   a. The adjusting screw
   b. The scavenge element
   c. The center bushing
   d. The drive spline

10) Which component is the largest in size?
    a. The scavenge element
    b. The pressure pumping element
    c. The oil pressure sensor
    d. The adjusting screw
For the following questions (11 – 15), label the components on the diagram with the
component names provided.

a. Lock Screw  
b. Oil Pressure Sensor  
c. Pressure Element Oil Outlet  
d. Silver Spanner Plug  
e. Scavenge Element Oil Inlet

11)