Winter 2007

The Effectiveness of Augmented Reality as a Facilitator of Information Acquisition in Aviation Maintenance Applications

R. Brian Valimont

Sathya N. Gangadharan
sathya@erau.edu

Dennis A. Vincenzi
vincenzd@erau.edu

Anthony E. Majoros

Follow this and additional works at: <https://commons.erau.edu/jaaer>

Scholarly Commons Citation

Valimont, R. B., Gangadharan, S. N., Vincenzi, D. A., & Majoros, A. E. (2007). The Effectiveness of Augmented Reality as a Facilitator of Information Acquisition in Aviation Maintenance Applications. *Journal of Aviation/Aerospace Education & Research*, 16(2). <https://doi.org/10.15394/jaaer.2007.1478>

This Article is brought to you for free and open access by the Journals at Scholarly Commons. It has been accepted for inclusion in Journal of Aviation/Aerospace Education & Research by an authorized administrator of Scholarly Commons. For more information, please contact commons@erau.edu.

THE EFFECTIVENESS OF AUGMENTED REALITY AS A FACILITATOR OF INFORMATION ACQUISITION IN AVIATION MAINTENANCE APPLICATIONS

R. Brian Valimont, Sathya N. Gangadharan, Dennis A. Vincenzi, and Anthony E. Majoros

ABSTRACT

Until recently, in the field of Augmented Reality (AR) little research attention has been paid to the cognitive benefits of this emerging technology. AR, the synthesis of computer images and text in the real world, affords a supplement to normal information acquisition that has yet to be fully explored and exploited. AR achieves a more smooth and seamless interface by complementing human cognitive networks, and aiding information integration through multi-modal sensory elaboration (visual, verbal, proprioceptive, and tactile memory) while the user is performing real world tasks. AR also incorporates visuo-spatial ability, which involves the representations of spatial information in memory. The use of this type of information is an extremely powerful form of elaboration. This study examined four learning paradigms: print (printed material) mode, observe (video tape) mode, interact (text annotations activated by mouse interaction) mode, and select (AR) mode. The results of the experiment indicated that the select (AR) mode resulted in better learning and recall when compared to the other three conventional learning modes.

INTRODUCTION

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

- It combines real world environments with computer images,
- It is interactive in real time, and
- It is registered in three dimensions (Azuma, 1997).

Little research attention in the area of augmented reality has been paid to the cognitive benefits of this emerging technology. 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 (Stedmon & Stone, 2001). Training systems as cost efficient as augmented reality are, of course, much concern to any practitioner in the aviation 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 test bed augmented reality system that addresses space frame 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 our 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 (Stone, 2001).

There are several issues that must be addressed in order to

Augmented Reality

construct the most efficient and effective learning and training methods utilizing the augmented reality system. This study intends 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 and 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, 1977). Though 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. 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). 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, & Thompson 1973; Tulving, Schacter, & Stark 1982; Murdock, 1983; & 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 (Lovelace, & Southall, 1983). Not to mention that spatial information is automatically processed when visual scenes are encoded into long-term memory (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 (Comstock, 1984; Cyrus, 1978; & Holding, 1976).

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.

METHODOLOGY

Participants

Subjects 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 experimental set-up used for the treatment conditions is a Silicon Graphics O2 Desktop CPU with operating system IRIX v 6.5. A Toshiba Color Stream color television model number 27A41 was used (see Figure 1). The television has 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 is a Sony color video camera (Model: CCX-Z11) that will feed the AR video-base

to the CPU to display the images. A manually manipulated turntable was used to rotate and display the work-piece. The software used for the augmented reality functionality is ARToolKit v. 2.431 from the University of Washington.

Figure 1. Experimental set-up used for Augmented Reality research

Design

The experiment is a $4 \times (2 \times 16)$ mixed measures design. There is one between-subjects independent variable, the mode of information presentation. This variable is broken up into four factors, video-based presentation, video-based interactive presentation, augmented reality presentation, and text-based presentation. The second independent variable is a within-subjects variable, length of time between instructional session and recall test. There are two levels of this variable, immediate post-instructional recall test, and a one-week, long-term post-instructional recall test. There is one dependent variable, amount of information correctly recalled, measured through the percentage score 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 is 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 for testing 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 every one, so it was tested and statistically controlled for using analysis of covariance. During a 20-minute interim called for in the BVMT – R procedures, subjects were given a brief demographic survey. They were 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 that their training group was provided with. Group 1 underwent video training, so they were given instruction on how to use the particular VCR they were provided with. Group 2 underwent video-based interactive training. They were given instruction on how to use the computer to bring up text boxes explaining the work-piece functions, as the video training ran on the computer monitor. Group 3 underwent video-based augmented reality training. They were given instructions on how to interact with the computer to find information on the functions of the work-piece. Lastly, Group 4 was given

Augmented Reality

print-based training. They were given instructions on the nature of the text they were reading, and the pictures provided.

The four groups then went through an eight-minute instructional session (see Figures 3 & 4), learning about the terminology, functions, and locations of the work-piece (an aircraft oil pump) and its components.

The subjects were then given a short three-minute bathroom break. When participants returned, they were given a recall test to measure how much knowledge they've 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.

Figure 2. Aircraft oil pump used as instructional work piece

Following the post-test a short interview was conducted to debrief the participant and record their opinions on the instructional mode they experienced. This concluded the first session. The estimated duration of session one was 45 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 the retention of information of the participant after one week without any rehearsal. Participants emailed their answers back to the experimenter. This test was again scored on the same percentage scale as the test taken immediately after the instructional session. This concluded session two and the experimental testing of research.

Data Collection

The data was collected on the two tests. The immediate post-instructional recall test and the long-term retention recall test measured 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. Using an analysis of covariance on the two independent variables, while controlling the variable of visuo-spatial ability, the authors hope to determine which instructional paradigm would be most effective for human learning and recall. If a significant difference is found through the ANCOVA, a Tukey HSD Post-hoc comparison will be used for further analysis.

Figure 3. Freeze frame of oil pump instructional video-base with augmented reality overlay

Figure 4. Freeze frame of oil pump instructional video-base with augmented reality overlay as oil pump is continued to rotate clockwise

Augmented Reality**Results**

The data were analyzed to determine the statistical significance of observed group mean differences. As can be seen in Tables 1 & 2, the AR 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. Mean test scores for immediate post-instructional recall test

Instructional Modes	Mean	SD	N
Augmented Reality	88.3	11.0	16
Video	82.9	13.1	16
Interactive Video	78.3	17.3	16
Print	77.5	10.3	16
Total	81.8	13.6	64

Table 2. Mean test scores for long-term post-instructional recall test

Instructional Modes	Mean	SD	N
Augmented Reality	80.0	13.9	16
Video	72.5	15.2	16
Interactive Video	69.2	22.0	16
Print	71.3	11.9	16
Total	73.2	16.4	64

The group means were statistically compared using a mixed measures ANOVA. The results of the ANOVA failed to find a statistically significant difference between the instruction group means, or the interaction between the instructional group and testing scores, $F(3,60) = 1.96$, *ns*, $F(3,60) = .37$, *ns*, respectively. A significant difference was found between the group means of the immediate recall test and the long-term test, $F(1,126) = 35.1$.

Discussion

Probably the most difficult challenge this experiment presented was the lack of data and theory from which the study could be constructed. There are only a handful of researchers looking into the field of augmented reality, and of those researchers, only a couple are interested in the human interaction. This caused the need for a great amount of innovation, especially concerning the design of the four instruction modes. There were no standards that dictate how each should be designed while keeping the information consistent throughout. Therefore, for the integrity of the experiment the display used and the information presented in all modes were identical, changing only the method of instructional presentation. This may have destroyed the inherent advantages and disadvantages of each method. To

truly find whether one method of instruction is better or worse than the other, they should be shown in their respective forms and compared against each other without striving for similarity. In such a case, the consistency of information presented in all instructional presentations poses a problem. This is an area that deserves more attention from the research community.

Though the results did not prove to be statistically significant, the authors gained knowledge concerning augmented reality and human learning. The authors found that the sample size proved to be smaller than optimal given that the statistical controls set upon the human visuo-spatial ability were not as effective as theorized. It's believed that the lack of correlation between human visuo-spatial ability and testing results is the major problem for non-significant results. With such a complex topic as human learning, it is unlikely that one sole characteristic has a dominant effect, as has been theorized in the past. It is most likely a combination of human traits that would have a major role in correlating a participant's results in augmented reality learning and information acquisition. Plans for experimentation with larger sample sizes are presently under way. →

Brian Valimont is currently a doctoral candidate at Virginia Tech. He was previously a graduate student pursuing his masters degree in the Department of Human Factors and Systems at Embry-Riddle Aeronautical University (ERAU). His specialization is in the area of Augmented Reality.

Sathya N. Gangadharan, Ph.D., P.E., C.Mfg.E., is a professor in the Department of Engineering Science at Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida. His areas of interest are in modeling, design and manufacturing of engineering systems specifically related to aerospace applications.

Dennis A. Vincenzi, Ph.D., is a Human Factors Research Psychologist at NAVAIR in Orlando. He was previously an Assistant Professor in the Department of Human Factors and Systems at Embry-Riddle Aeronautical University (ERAU) in Daytona Beach, Florida. He was also a Post Doctoral Fellow at the Naval Air Warfare Center Training Systems Division (NAWCTSD) in Orlando, Florida for research in military aviation.

Anthony E. Majoros, Ph.D., CPE, is a Senior Principal Engineer Scientist and Technical Fellow in Crew Systems Technology at the Boeing Company, California. He specializes in the development of image-based communication technologies in the company's Phantom Works division, and provides crew systems design and development support to space and aviation programs.

REFERENCES

- Azuma, R.T. (1997). A survey of augmented reality, *Presence*, 355-385.
- Baldwin, T.T., & J.K. Ford. (1988). Transfer of training: A review and directions for future research, *Personnel Psychology*, 63-105.
- Bjork, R.A., & E.L. Bjork (Eds.). (1996). *Memory*, San Diego, Academic Press.
- Bower, G. (1972). Mental imagery and associative learning, *In Cognition and Learning and Memory*, New York, John Wiley.
- Briggs, G.E. (1969). *Transfer of Training*, *In Principles of Skill Acquisition*, New York, Academic Press, 205-234.
- Comstock, J.R., Jr. (1984). The effects of simulator and aircraft motion on eye scan behavior, Santa Monica, CA, *Human Factors Society 28th Annual Meeting*, 128-132.
- Cyrus, M.L. (1978). On the role of motion systems in flight simulators for flying training (AFHRL-TR-78), Williams Air Force Base, AZ, Air Force Human Factors Research Laboratory.
- Fisher, R.P., & Craik, F.I.M. (1977). Interaction between encoding and retrieval operations in cued recall. *Journal of Experimental Psychology: Human Learning and Memory*, 3, 701-711.
- Holding, D.H. (1976). An approximate transfer surface, *Journal of Motor Behavior*, 1-9.
- Lintern, G. (1991). An informational perspective on skill transfer in human – machine systems, *Human Factors*, 25 1-266.
- Lovelace, E.A., & S.D. Southall. (1983). Memory for words in prose and their locations on the page, *Memory & Cognition*, 429-434.
- Murdock, B.B. Jr. (1983). A distributed memory model for serial-order information. *Psychological Review*, 90, 316-338.
- Neumann, U., & A. Majoros., (1998). Cognitive performance, and systems issues for augmented reality applications in manufacturing and maintenance, *IEEE Virtual Reality Annual International Symposium (VRAIS '98)*.
- O'Shea, A.M., C.A. Cook, & A.L. Young. (1999). The use of augmented reality in the provision of training feedback, Hague, Netherlands, *International Training & Education Conference*, 328-336.
- Pezdek, K., & G.W.Evans. (1979). Visual and verbal memory for objects and their spatial locations, *Journal of Experimental Psychology: Human Learning and Memory*, 360-373.
- Rawles, R.E. (1978). The past and present of mnemotechny, *In Practical Aspects of Memory*, London, Academic Press.
- Stedmon, A.W. & Stone, R. (2001). Re-viewing Reality: Human Factors Issues in Synthetic Training Environments. *International Journal of Human Computer Studies*.

- Stone, R. (2001). Virtual reality for interactive training: and industrial practitioner's viewpoint, *International Journal of Human – Computer Studies*, 699-711.
- Tulving, E., & Thompson, D.M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 80, 352-373.
- Tulving, E., Schacter, D.L., & Stark, H.A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Human Learning and Memory*, 8, 336-342.
- Yates, F.A. (1966). *The Art of Memory*, Chicago, University of Chicago Press.
- Zachary, W., J. Ryder, J. Higginbotham, & K. Bracken. (1997). The use of executable cognitive models in simulation-based intelligent embedded training, Santa Monica, CA, *Human Factors and Ergonomics Society 41st Annual Meeting*, 1143-1149.