Augmented Reality in Spatial Ability Development: A Concept Study

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ABSTRACT - *This paper examines the use of desktop augmented reality as a visualization aid. Participants were given a series of tasks to complete in an interactive augmented reality environment. Upon completion of the tasks, the participants were asked to complete a survey to measure their perception of the benefits of the augmented reality technology. Initial results showed that all participants felt that the use of the augmented reality technology benefitted their spatial visualization, although technological challenges needed to be overcome. A full description of the research study is presented, along with results, potential ramifications for instruction in the engineering graphics field, and suggestions for future research in this area.*

I. Introduction

In many professional fields, including engineering and technology, the ability to be able to 'see' in three dimensions continues to be of great importance. Many studies and much significant research have examined the nature of spatial ability and its impact in graphics education, as well as the challenge of teaching those who struggle with spatial constructs. Several remediation solutions utilizing traditional instructional methods and technologies have been applied in the past by members of the Engineering Design Graphics Division with varying levels of success. As technology continues to progress, options for new instructional methods arise that provide potentially effective solutions to the challenge of developing spatial skills in our students. This paper examines one such novel technology and application as a proof of concept: desktop augmented reality as a visualization aid. The technology used in the study included commonly available hardware and open source software. The focus of the study was to measure participants' perception of spatial ability improvement due to exposure to augmented reality interaction. A secondary purpose was to measure participants' comfort level in using augment reality in a laptop computer environment. Finally, the researchers hoped to explore the possibilities and difficulties in using current low level augmented reality technology in the representation of computer generated three dimensional objects. Research into and application of augmented reality is a growing niche in the spectrum of virtual reality, which stretches from simple desktop applications through fully immersive environments. Applications of this technology are expanding in the areas of entertainment, construction, manufacturing, and education/training among others.

II. Background

Spatial Ability

Spatial ability has been defined in many ways over the many years and many research studies that have explored this construct (Connolly, 2007). By whatever name or description, the ability to mentally envision, retain, and manipulate three dimensional images (Lohman, 1979) remains an important cognitive ability for many tasks in the world we live in (Smith, 2003; Sorby, 2000; Sorby & Baartmans, 1996; Sun & Suzuki, 1994). Spatial skills are often assessed as a means of measuring abilities and potential for various professions or academic fields (McGee, 1979; Miller, 1992; Smith, 1964; Strong & Smith, 2002). The depth of research into spatial ability is considerable and includes the realms of psychology, childhood development, neurological constructs, and many cognitive sciences. Although the results of these many studies and trends in the field have differed over the decades, there is general agreement on several points, including that 'spatial ability' is actually several different cognitive skills involving spatial orientation and visualization (Eliot & Smith, 1983; Lohman, 1979; McGee, 1979). However, there is still disagreement among experts regarding the nature of what we call spatial ability.

One area of considerable disagreement in this field has involved whether spatial ability can be developed or enhanced. Many professionals and educators in the field of engineering and computer graphics are strong supporters of the position that these skills can be improved (Miller, 1996). Many traditional engineering design graphics practices, such as drafting, sketching, and the use of orthographic projection have long been viewed as excellent tools in spatial development (Field, 1999; Sorby, 1999; 2001; 2005; Tsutsumi, 2005). Computer-based methods in CAD and image rendering also appear to have credence in this development process (Contero, Company, Saorin, & Naya, 2006; Sexton, 1992; Smith, 2003).

Virtual/Augmented Reality

Virtual reality (VR) is a broad and encompassing term that is often used in discussions of technological applications in a wide variety of fields. However, defining virtual reality can be a nebulous and confusing task, depending on the source and application of the technology. Descriptions can include many aspects of computer-generated environments and subsumes various levels of immersiveness, such as desktop VR, semi-immersive or augmented VR, and fully immersive VR (Fällman, 2000). Although many researchers only considered VR from a fully immersive, completely artificially created, multi-sensory paradigm, others (Billinghurst, 2002; Kaufmann, 2003; Szalavari & Gervautz, 1997) have examined the virtual experience from an augmented perspective – a combination of artificial and existing environments. Youngblut (1998) cautioned that to limit the definition of virtual reality only to immersive environments, or to describe presence only in terms of immersion, would overlook the potential advantages of non-immersive VR systems. One benefit of augmented reality includes the ability to display a virtual three dimensional object along with and as part of a real environment. Milgram (1994) described a scale that identified how augmented reality and virtual reality are related along a reality continuum. This scale referred to the distinct methods of visualization available to a single perspective (see Figure 1).

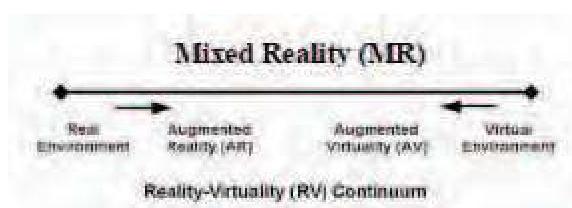

Figure 1. Milgram's Reality-Virtuality Continuum

Modern usage of augmented reality include applications such as medical imaging, product design, and entertainment. In engineering graphics applications engineers, designers, and clients can now describe a model and present/critique it through a augmented reality teleconference.

The technology involved in creating an augmented reality system is fairly common, yet there are several ways of presenting these system environments. The required materials involve a video capture device, a display device, a computer to capture the video feed, overlay the geometry and display, and a grid or marker that may be captured by the camera to interpret perspective, location, and angle of the real world. The two different methods in which this can be arranged are:

- Using a see through head mounted display with capture device attached to the display.
- Using a monitor and camera in which the camera and monitor are positioned without any attachment to the viewer.

The head mounted display devices may also be split into two different categories: optical-see-through and video-see-through. The simplest version of an optical see-through display employs a mirror beam splitter to allow light to pass through while at the same time reflecting key lights from a separate direction. If oriented properly, the beam splitter will reflect the image of a computer display in front of the user's eye while still allowing light from the surrounding world to pass through (Feiner 2002). For the sake of cutting cost and speed of development, this research utilizes a monitor-camera setup for greater accessibility and usability (see Figure 2). This method is also at a greater advantage if there are multiple viewers interacting or viewing the AR system.

Figure 2. Monitor-Camera Augmented Reality Setup

III. Method

Procedure

The study was a qualitative assessment of students' perception of an augmented reality interface. The participants were asked to sit in front of a computer monitor that displayed a live video feed captured by a camera facing the table in front of the subject. On the table, subjects were presented with a set of cards with symbols on them. As the camera captured the symbols on the cards, superimposed computer generated, three-dimensional geometry was displayed on the monitor. These three dimensional shapes were located above the card symbols on the monitor image.

Prior to the actual tasks being presented, the participants were shown a single card with an overlaid three-dimensional computer generated geometric shape.

This procedure allowed the students to familiarize with the interface. The participants were given 60 seconds to become accustomed to the interface or could request to begin the first task earlier, if desired. The students were then given a total of five minutes to complete the following tasks before beginning the survey.

In order to complete the study, students were presented with a set of cards, each with its own respective geometric shapes. The three dimensional augmented reality shapes were superimposed on the two dimensional card images as described above (see Figure 3). The participants were asked if the geometric shapes were identical or dissimilar. These shape objects were obtained from spatial ability tests, such as the Vandenberg Mental Rotations Test (see Figure 4) and the Purdue Spatial Visualization Test-Rotations.

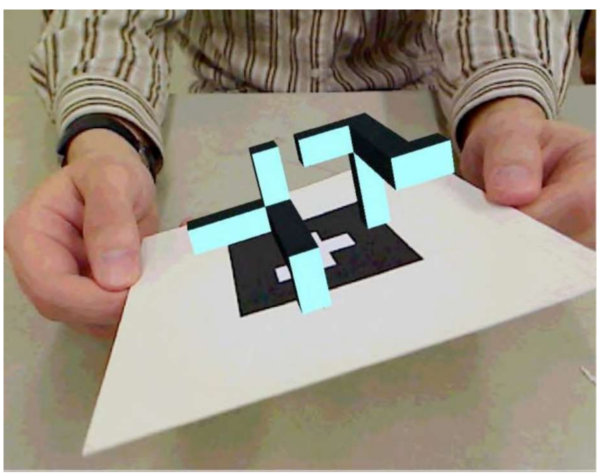

Figure 3. Example Comparison Task

If the students completed the comparison task with time to spare, they were given the option of completing additional tasks in which they were asked to rotate and translate the cards in order to arrange computer generated three dimensional geometric shapes into a given configuration. The purpose for this was to have the participants become accustomed to rotating and translating the markers to gain a better understanding of

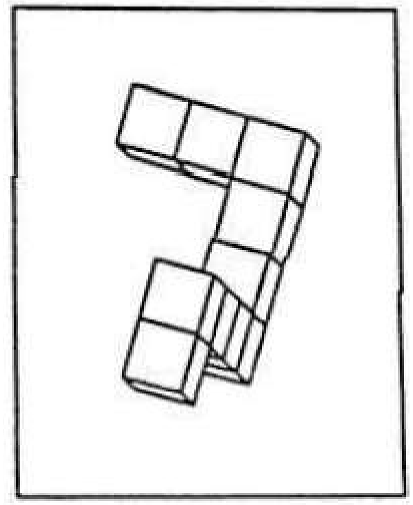

Figure 4. Example from the Vandenberg Mental Rotations Test

how those markers correlate directly with how the represented objects are superimposed on the image. Following these tasks, or after the allocated time expired, the subjects were asked to fill out a survey (See Appendix 1). 21 participants participated in the research, ranging in age from 18 – 25 years old. All were students at Purdue University, from a variety of academic majors.

Hardware & Software

For this study, the researchers used a standard LCD monitor from a laptop with specifications not exceeding single core 1.00GHz, 512MB RAM. A Logitech QuickCam 9000 was utilized for the video recording. The software used in this study is compatible with any web cam with proper drivers installed with efficiency being proportional to the computer's graphic capabilities. The application for this research was developed with a base from ARToolkit GNU Edition, OpenGL, and VRML libraries. ARToolkit is an open source project that consists of a software library for building AR applications. This library allows the application to calculate the position of the marker from the perspective of the camera. This is done by calculating the position, size and angle of the marker to determine its location. These markers consist of printed squares with symbols labeled on them (see Figure 5). These symbols are stored in the application and are used to determine which objects to load onto the markers.

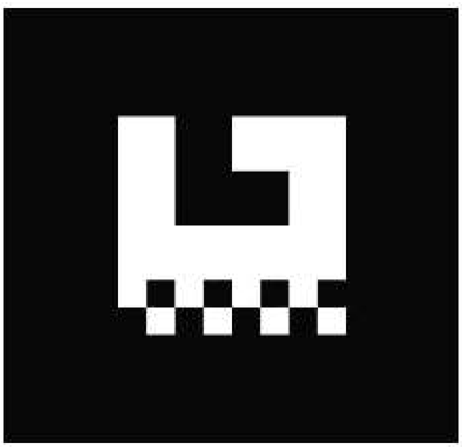

Figure 5. Marker Example

IV. Results

There were four Likert scale questions in the survey that examined participants' perception of the augmented reality interface. Preliminary analysis of the data from the responses to these questions indicated that students felt that further use of augmented reality technology could help their comprehension of three dimensional geometry (See Table 1).

	SD	D	U	A	SA	Mean
Do you think further use of Augmented Reality can increase your understanding of geometric views (orthographic, isometric, etc.)?	0	0	1	16	4	**4.14**
Would you be more comfortable interacting with computer generated geometry through this interface instead of using a mouse and keyboard?	0	5	3	5	8	**3.76**
Do you think this would be a useful application in a class environment?	0	0	2	9	10	**4.38**
Does the lack of physical tactile feedback make it more difficult to understand the model?	1	9	7	4	0	**2.67**

Table 1. Survey Responses

The response to Question 1 indicated that the participants agreed that the use of augmented reality could be helpful in understanding of three dimensional objects (Mean response = 4.14 out of 5.00). The second question results indicated that most of the participants preferred the augmented reality interface (3.76 mean score), but there were also five respondents that preferred a more traditional user interaction. For Question 3, the participants felt strongly that an augmented reality application would be a useful tool for academic settings (4.38 mean score).

Although the mean score for Question 4 indicated that students favored the augmented reality feedback, there was sufficient responses to the contrary to indicate that some participants still would favor some sort of haptic/tactile feedback to assist in their understanding the image geometry.

Students also responded to seven open ended short answer questions to further examine their perceptions of the augmented reality technology. The responses to these questions have not been analyzed in depth at this time, but in general the responses seem to indicate that the participants quickly became comfortable with the augmented reality interface. The responses indicated a strong interest in the augmented reality technology and a generally positive stance towards the utilization of augmented reality in completing the delineated tasks. The question "If you had an opportunity to use this technology in your daily work/field of study, would you?" generated a very wide range of responses. The purpose of this question was to encourage the participants to visualize the application of augmented reality into their own context. It would appear that more research and clearer demonstration of the potential uses of augmented reality technology may be necessary to clarify and gain insight into the reason for such a wide variation in perception for this question.

V. Future Research

The results of this study indicate that there might be significant benefit to applying augmented reality technology in educational settings. It is recommended that further testing be done with the equipment used in this study, in both more detailed research of spatial comprehension and broader applications in academic subject matter. Further studies could also examine impact of augmented reality on learning style preference, as a remediation tool in various subject areas, and in special education and/or gifted education scenarios. As more data is generated, quantitative analysis techniques could also be used to measure the effectiveness augmented reality as a visualization tool. Analysis of the impact of the technology by specific demographics such as gender, culture, age, and experience may also prove beneficial.

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Appendix 1. Survey Instrument

Visual Interpretation through Augmented Reality Survey:

SD = Strongly Disagree
D = Disagree
U = Undecided
A = Agree
SA = Strongly Agree

	SD	D	U	A	SA
Do you think further use of Augmented Reality can increase your understanding geometric views (orthographic, isometric, etc.)?					
Would you be more comfortable interacting with computer generated geometry through this interface instead of using a mouse and keyboard?					
Do you think this would be a useful application in a class environment?					
Does the lack of physical tactile feedback make it more difficult to understand the model?					

- Is the interaction similar to what you believe the interaction with a physical object would be and why?
- Did you feel like you needed further instructions?
- What did you like the most and why?
- If you had an opportunity to use this technology in your daily work/field of study, would you?
- What changes would you make to this interface?
- What did you find difficult to use?
- What was most intuitive? What wasn't?