Investigation of the Effects of an Autostereographic Virtual Environment on Recall in Participants of Differing Levels of Field Dependence

Michael Wilson Moore

Virginia Polytechnic Institute and State University

February 3, 2006

Dissertation submitted to the Faculty of the

Department of Teaching and Learning

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In

Curriculum and Instruction

Dr. David M. Moore, Chair
Dr. John K. Burton
Dr. Barbara B. Lockee
Dr. Kenneth R. Potter
Dr. Jeffrey T. Ogle

Blacksburg, Virginia

Keywords: Autostereoscopic, Virtual Environment,
Field Dependence Independence

Investigation of the Effects of an Autostereographic Virtual Environment on Recall in Participants of Differing Levels of Field Dependence

Michael Wilson Moore

(Abstract)

Stereographic virtual environments display data in such a way that a user perceives objects within the displayed environment to be separated in depth from the display itself. The effectiveness of stereographic virtual environments as learning tools has been evaluated relative to factors such as multidimensional cues, user interaction, and learner characteristics. This study has examined the relationship between two evaluative factors: the presence of stereographic depth cues and field dependence, a learner characteristic associated with performance on visual tasks. Adult learners were identified on a field dependence continuum based on scores on the Group Embedded Figures Test. Each student received instruction related to the heart using stereographic materials or nonstereographic materials, depending on assignment to treatment group. All participants were given two tests, identification and terminology, following this instruction. The scores on the combination of these tests, denoted as the Modified Total Criterion Test (MTCT), represented the level of visual recall relative to the instructional materials reviewed. Analyses of variance revealed an interaction effect between the level of field dependence and the presence of stereographic depth cues within a virtual environment such that field independent participants scored higher on tests of visual recall within stereographic conditions versus nonstereographic conditions and field dependent participants scored lower within stereographic conditions versus nonstereographic conditions.

Press on. Nothing can take the place of perseverance.

Talent will not. Nothing is more common than unsuccessful men with talent.

Genius will not. Unrewarded genius is almost a proverb.

Education will not. The world is full of educated derelicts.

Persistence and determination alone are omnipotent.

The slogan "press on" has solved, and always will solve, the problems of the human race.

- Calvin Coolidge

DEDICATION

This is for my grandfather who told me early on: “get the most education you can because it is something no one can ever take away from you.”

This is for my grandmother who believed that the purpose of a life is to improve the lives of others.

This is for my father whose work ethic taught me to always approach challenges with determination and intensity.

This is for my mother who taught me about perseverance, hope, and faith.

I struggle everyday to live up to the ideals that you have all shown me. You should view this accomplishment as your own because it would have never happened without you.

ACKNOWLEDGEMENTS

There were many people who deserve credit for making this accomplishment possible.

I want to thank Dr. Burton, Dr. Ogle, Dr. Lockee, and Dr. Potter for both their insights and their patience during the dissertation process. I especially want to thank Dr. Moore for his personal dedication as he stayed on with me as my chair well into his retirement.

I owe a lot to the entire Virginia Tech community. My graduate assistantship at Newman Library gave me the means to work towards both my personal and professional goals. Without the support of the people there, college, let alone graduate school, would never have been an option.

Dr. Carole Inge of the NASA VT STEM group always believed that I could build, find, or fix whatever the project demanded. The confidence and skills I've gained from my consulting work with her at Longwood University and later at Virginia Tech have made me a better professional. I also owe a lot to my colleagues at each of these positions such as Vicki Spake, Jennifer Stevens, Bill Wilson, and many others.

Dr. Frank Boster at Michigan State and his wife Linda provided endless answers to my questions regarding statistics, research, academia, and life in general.

Dr. Carmel Vaccare at Radford University was the first to suggest that virtual environments might be a good fit for my research area. My professional career would look very different without his direction.

The logistics of collecting data using stereographic screens with adult learners presented a challenge and could not have been managed without the help of several people and organizations:

The funding for this work was arranged by Dr. Yvonne Thayer at the Office of Adult Education at the Virginia Department of Education and Dr. John Wenrich and Dr. Joy Colbert in the Virginia Tech Engineering department.

Dr. L.B. Berg at the Virginia Educational Technology Alliance (VETA) at the College of William and Mary gave me the opportunity to design and secure the hardware configuration because of his commitment to the importance of evaluating new technologies in education. Karen Richardson followed through to support me during the entire process. The Institute for Teaching through Technology and Innovative Practices (ITTIP) at Longwood University and the Southside Virginia Regional Technology Consortium (SVRTC) also provided hardware assistance during this project.

The materials used in this study are based on those created by Dr. Frank Dwyer at Penn State. His work has been used in visual research for decades and provided the means to make this experiment possible.

Dr. Tom Pinelli and the staff at the NASA Center for Distance Learning were instrumental in adding a third dimension to the Dwyer materials during the modification process.

Amy Lammerts and the staff at the Southern Virginia Higher Education Center and Sue Garlock and the staff at the Prince William County Adult Education Center assisted in arranging for the subjects needed to complete this study as well.

Finally, anyone who knows me knows that I have the best group of friends and family that a person could ask for. All along the way, they have helped me to stay on track and focused on this goal and all the opportunities it brings. I want to thank them and all others who kept me going along the way.

TABLE OF CONTENTS

LIST OF FIGURES

.

LIST OF TABLES

CHAPTER 1: REVIEW OF LITERATURE

Visual media such as digital animations or printed illustrations can be an effective means of communicating a concept to a learner (Levin, Anglin, & Carney, 1987; Carney & Levin, 2002). For this reason, instructors and instructional designers incorporate visual media such as pictures or videos into educational materials. Based on the current state of technological capability, the majority of illustrations in both print and digital instructional media are developed in two-dimensional format. There are, however, many concepts related to three-dimensional phenomena that are difficult to represent within a traditional two dimensional illustration (Kettle, 1999; Salzman, Dede, Loftin, & Chen, 1999). For instance, content domains such as physics, chemistry, and biology contain concepts that can best be described using three-dimensional representations.

Stereographic virtual environments (SVEs) are a type of visual media, which can depict three-dimensional concepts to a learner through interactivity and immersive three-dimensional display systems (Cruz-Neira, Sandin, & DeFanti, 1993; Davis & Hodges, 1997; Bowman, Hodges, Allison, & Wineman, 1999; Salzman, et al., 1999) There is speculation as to the role that will be played within education by stereographic virtual environments and other complex visual media made possible by evolving processing and display capabilities (McLellan, 2004). However, the question remains as to whether these complex visual applications provide a more effective means of instruction than simpler two-dimensional illustrations.

In describing meta-analyses of media evaluation, Clark (1983) has suggested that assessing the effectiveness of an instructional medium by contrasting one medium with another often leads to erroneous comparisons such as radio to television. These media comparison studies do not accurately assess the impact of a medium because of errors in their design (Lockee, Moore, & Burton, 2001).

"The comparison design inherently assumes that each medium is unique and can affect learning in some way. The confounding factor here is that each medium consists of many attributes that may affect the value of the medium's instructional impact" (Lockee, Moore, & Burton, 2001, p.61).

A more accurate evaluation of effectiveness then is gained by evaluating the impact of specific attributes of a medium such as color or resolution. An analysis of the factors related to the evaluation of stereographic virtual environments as a learning tool requires a closer examination of the medium itself.

Stereographic Virtual Environments

Virtual environment (VE) is the accepted term for the field of research related to files or applications that allow a user to view a synthetic version of a concept, real or imagined (Cruz-Neira et al., 1993; Bowman, et al., 1999; Salzman et al., 1999). Stanney and Zyda (2002) have defined a virtual environment as "a three-dimensional data set describing an environment based on real world or abstract objects and data" (p. 5). This definition describes virtual environments essentially as a type of software. However, virtual environments and the common parallel term, *virtual reality,* are also linked closely with hardware such as three-dimensional display devices and motion platforms (Durlach & Mavor, 1995; Vince, 2004). A SVE is a virtual environment displayed in such a way that the view of the user is given depth through the creation of a different image for each retina (Davis & Hodges, 1997). By causing the mind to perceive depth where none exists, SVEs give the appearance that objects are beyond the plane of the display itself. In order to understand the mechanics behind the display technology associated with SVEs, it is necessary to closely examine the physiology behind human perception of depth.

May and Badcock (2002) as well as Howard and Rogers (1995) have described the processes within the brain responsible for the perception of depth. Stereopsis is the perception of depth due to the relationship of two different views being combined in some way. Most humans see the world through two distinct visual lenses within the right and left eyes. This can be demonstrated by observing a stationary object at a short distance and closing one eye and then the other. The observed object will appear to change position despite remaining motionless. Although the image from the left eye differs from that of the right eye, the mind is able to process the two images and synthesize them into one distinct view which includes information relative to the depths of objects within the visual field. The difference between these two views is defined as binocular disparity (DeAngelis, 2000). The interpretation of these two views occurs as part of the brain's systematic analysis of visual stimuli.

The two different views of the left and right eyes are based on the light captured on the retina of each individual eye (Howard & Rogers, 1995; May & Badcock, 2002). An optic nerve transmits these views as signals to the brain where there is a reference point that provides a marker for how these two views are related. This reference point, the *horopter,* is the point at a distance from the eyes where the views from the left eye and from the right eye merge (Adler, 1987). It is from this point, the region of binocular fusion, where the brain accommodates and merges the two images into a single, coherent field. Objects that have three dimensions contain some portions that lie in front of or behind the horopter and, therefore, cannot be completely merged. The brain recognizes these areas of difference in terms of horizontal disparities between left and right retinal images, and the person thus perceives the depth and volume of the object rather than just the area.

In order to create a stereographic image which a typical user can view, a display must contain accurate information relative to the horizontal disparities that exist between the left and right eye images (Davis & Hodges, 1997). It is possible to predict and contrive these disparities within images based on the relative uniformity of the depth perception process in humans (May & Badcock, 2002). For instance, the specific mathematics with which the brain processes the retinal horizontal disparity differs only slightly based on the distance between the eyes and this distance which is often referred to as interoccular distance and is relatively consistent throughout the population (Howard & Rogers, 1995). This consistency makes it possible to predict the degree of difference that would exist between a typical user's left eye view and right eye view of a scene and develop prepared images accordingly (Thwaites, 1993). Stereographic displays can then be used to deliver the prepared left and right eye images to the appropriate eye of the user thereby mimicking the appearance of three-dimensional objects within the constructed scene. The wide array of techniques used to deliver images to the appropriate eye range from head-mounted display mechanisms to relatively traditional desktop-based systems.

Stereographic Display Techniques

A display technology creates stereoscopic viewing conditions by providing two images of the same scene with fusible retinal differences (May & Badcock, 2002; Thwaites, 1993). For example, Smith, Connel, and Swift (1999) have described the process associated with the common symbol of three-dimensional media, the red and green anaglyph glasses. Here color was used as a means of discriminating the left eye's image from the right eye's image by allowing only red images to reach one eye and only green to reach the other. The observer wearing the corresponding glasses perceived a merged projection with apparent depth. Smith, et al. used anaglyph displays to present structural depth information found in atomic force microscope images. Because this method requires rendering every image into two distinct colors, much of the potentially valuable color information within the visual is lost. Therefore, a more complex approach is needed to deliver a distinct image to each eye without losing color information.

For instance, within some stereographic display techniques, multiple display devices are used to distribute a separate image to each eye. Because there is more than one display device, steps must to be taken to ensure each eye receives the signal from the appropriate display. One method of achieving this fidelity is to reduce the distance between each eye and the corresponding display device. This reduction of distance results in a configuration called a head-mounted display (HMD) in which display devices are mounted directly in front of the user's eyes (Pertaub, Slater, & Barker, 2002). HMD's require the user to view the display apparatus at such a close proximity that the field of view is completely covered by the display. HMD's can consist of a combination of two small display systems such a liquid crystal displays (LCD's) mounted within an apparatus meant to be worn by the user directly in front of the eyes (Arnold, Farrell, Pettifer, & West, 2002). Current barriers to widespread use in education include size, discomfort, limited resolution, and expense. There are alternative stereographic display techniques, which do not require the user to wear the display device itself. Instead, these techniques utilize filters that are worn directly over the eye in glasses and ensure the appropriate signal reaches each eye.

Cruz-Neira et al. (1993) have described a filtering system based on rapidly fluctuating images. In this system, a process called active stereographic projection uses display devices that alternate between showing the right eye view and the left eye view. The mind perceives these views as overlapping, because the views are alternated so quickly. To change this overlapping view to a stereoscopic view, the user wore a set of shutter glasses that opened one eye and closed the other eye's view intermittently. Once this shutter effect was synchronized through electronic signals with the right-left eye alternation pattern of the projector, the observer perceived one stereoscopic view rising out of the two-dimensional screen. While the visuals generated by an active-shutter glass-projector system are impressive, their use particularly in educational environments is limited due to the fact that stereoscopic shutter-based projectors are cost prohibitive to purchase and maintain in working order. This projection method also requires users to wear larger glasses which employ shutter glass technology, characterized by many users as uncomfortable.

Steinwand, Davis, and Weeks (2002) have described a more cost-effective method for creating a stereographic display through the use of smaller thinner polarized light filters to create separate images for each eye. The first step in this process was to superimpose two liquid crystal display (LCD) images onto one another as the right and left eye signals. This can be done with two monitors and a mirroring system or two LCD projectors and a positioning device. Polarizing filters were used to put one signal into one direction of polarization and the other signal into the reverse direction of polarization. Once these processes were in place, the only hardware the user needed to wear was a pair of polarizing sunglasses. The value of this technique within an instructional setting is that the devices the user wears are lighter, cheaper, and more durable than those of any other solution. It is still limited, however, to many of the same space constraints as the other projection methods. For this reason, as well as the set-up time involved, stereographic display through polarized projection is generally associated with group audiences rather than individual users. The demand for a stereographic display that is both cost effective and comfortable for the single user has driven research in the autostereoscopic domain.

The term *autostereoscopic* denotes a stereoscopic display, which does not require the user to wear any form of lenses to generate the required retinal disparity. Sharp Laboratories of Europe, Ltd. (2003) have described an autostereoscopic display designed for a single user. Binocular disparity was instead formed by slits of light approximately 60 micrometers in width, with a positional accuracy of less than 1 micrometer. The fact that these slits of light were so small and exactly positioned allowed the display to essentially paint each eye of the user with a different image. The slits were created by micro-optical components within layers of multiple liquid crystal displays which selectively admitted and retarded light, creating transmissive columns that reach the user and nontransmissive columns that did not. This creates a relatively large zone of effective stereoscopic viewing directly in front of the display at a distance of approximately 0.5 meters. Individual stereographic displays allow the use of SVE applications without extending beyond the space needed by a common desktop computer. This is another example of the variety of display arrangements available for display of SVEs.

As explained, the range of stereographic display systems accommodates a wide array of applications. SVEs can be displayed within a group projection setting or on an individual desktop. The end result is the generation of stimuli that users perceive as extending beyond the surface of the display. The variety of display options makes possible many diverse applications that utilize the immersive depth present within SVEs.

Applications of Stereographic Virtual Environments

SVEs are useful in visualizing data through translating variations in numeric data into forms that can be seen with the human eye such as color, depth, or shapes (Bowman et al., 1999). Mapping data in such a way allows an observer to visualize the data in a new form and can often reveal patterns that had not been seen before. Stereographic visualization using SVEs creates a modeling system for researchers to visually assess relationships within data at multiple angles (Gobbetti, Pili, Zorcolo, & Tuveri, 1999). By allowing the visualization of scientific data sets in three-dimensional form, SVEs often provide a more contextually accurate representation of the physical world than two-dimensional visual analysis. Because of these capabilities, SVEs have been utilized within data-intensive disciplines such medicine, geology, and engineering.

SVEs can give medical personnel several advantages when evaluating patient data. SVEs permit doctors and medical researchers to visually assess data gathered from portions of the body such as the human vascular system that would be difficult if not impossible to physically observe due to risks associated with major surgery (Gobbetti et al., 1999). Surgeons can prepare for a potential operation by simulating the associated tasks beforehand within an SVE. Additionally, SVEs can improve the ability of medical personnel to recognize important medical conditions such as the location, size, and shape of a tumor (Hernandez, Basset, Bremond, & Magnin, 1998). The use of SVEs as aides in visual differentiation also extends to other disciplines such as geology.

Nesbitt, Gallimore, and Orenstein (1999) and Sumrow (2002) have described applications of SVEs to assist geologists within commercial firms interested in determining the location of potential petroleum deposits. The revenue stream associated with locating a new petroleum deposit is considerable but is often superceded by the funding needed to locate the resource and develop a functioning well. This was the impetus for providing researchers with SVEs as additional tools for visual analysis of data. Data sources such as seismic activity are geocoded in three dimensions to provide a visual representation that can be utilized in geophysical analysis. The SVEs described by Nesbitt et al. also created a means of collaboration by allowing a visual display that analysts from multiple disciplines such as geophysicists, oceanographers, geochemists could use together to view and describe data. The use of SVEs as a means for collaboration is also present in the engineering domain.

Automotive engineering requires teams of designers and engineers to generate prototypes of vehicles based on their collective vision of the final product. Each team member is responsible for contributing their own ideas to the project related to specific disciplines ranging from aerodynamics to consumer marketability. Using physical models to describe repeatedly the features of thousands of different versions of the same vehicle is time intensive and costly. Waurzyniak, (2000) and Farish (1999) have desribed how SVEs have provided an alternative that allows members of various design teams to develop digital representations of their ideas to be presented to their colleagues. Virtual environments allow these representations to be created to scale and stereographic displays create the opportunity to view them as if they were physical three-dimensional models. Commercial automotive engineering teams at General Motors, Ford, and DaimlerChrysler have begun using this system of “virtual prototyping” as means of reducing costs, reducing prototype production time, and improving transition from design to production Waurzyniak, (2000). Waurzyniak has also reported that engineers in other industries have made similar adjustments to their design processes at companies such as Boeing and Caterpillar. In each of these design applications, SVEs have allowed engineers to communicate concepts in three-dimensional visual form. This technique is also useful to instructors and designers within the domain of education and training because of its effectiveness in enabling visual communication of complex concepts.

Stereographic Virtual Environments in Education and Training

Using stereographic virtual environments as a means to deliver instruction can be advantageous in a variety of ways. Virtual environments can provide students the capability to practice skills within contextual situations they may never physically encounter (Roussos, Johnson, Mohler, Leigh, Vasilkas, & Barnes, 1999; Salzman et al., 1999; Johnson & Leigh, 2002). There are concepts that cannot be experienced directly in the physical world such as subatomic phenomena but which could be explored through the use of a virtual environment (Bowman et al., 1999; Roussos et al., 1999; Salzman et al., 1999). SVEs used in instruction are a varied set of applications which include both static three-dimensional diagrams and shifting virtual worlds full of motion (Kettle, 1999; Trindade, Fiolhais, & Leandro, 2002). An instructor can use SVEs to illustrate ideas to a class of students, to provide a guided tour of a concept, or to create a setting for independent learner collaboration (Keefe, Acevedo, Moscovich, Laidlaw, & LaViola, 2001; Morgan, Kriz, Howard, das Neves, & Kelso, 2002; Roussos et al., 1999). Examining examples developed for instruction provides better comprehension of the range of capabilities that can be provided within an SVE.

Kettle (1999) has described how SVEs aid the teaching of complex concepts, such as quantum chemistry, which require understanding of movement and interaction of particles among three-dimensions of space. Traditional diagrams entail multiple two-dimensional views, which a learner must mentally orient relative to one another to fully understand the concept.

Kettle (1999) has demonstrated how SVEs have allowed these multiple diagrams to be combined into a more representative three-dimensional form. A set of three static diagrams, which describe the orientation and movement of particles in three-dimensional space, can be combined in a single SVE. Thus learners were able to use the SVE as a visual tool to organize the spatial information of the particles. Educational SVEs can also extend beyond three-dimensional static diagrams to applications that include movement and interactivity.

Trindade et al. (2002) have described the use of an SVE called Virtual Water, which offers students the opportunity to explore concepts such as atomic orbitals, phases of matter, and phase transitions related to the water molecule. Learners were able to view the objects within the SVE at multiple angles as movement associated with chemical processes occurred. Stereographic images of crystalline structures allowed learners to identify patterns within the shifting molecules. The designers of Virtual Water intended for components such as the portion of the SVE dealing with quantum mechanics to give a predefined environment in which learners could observe instructional concepts such as orbital symmetry. Besides being used as prepared instructional content, SVEs can also be used as locations for synchronous instruction.

Just as instructors have traditionally used tools such as paper or chalkboards to illustrate concepts to students, SVEs can allow the depiction of visual concepts in realistic three-dimensional space. For instance, Keefe et al. (2001) have described an SVE that contains real-time creation of content by both instructors and students. Users within the SVE were able to use input devices which acted as digital paintbrushes to construct images within three-dimensional spaces. Once content was created, users could view it from multiple angles by moving within the

SVE. This ability to control viewpoint within certain SVEs creates additional opportunities for the instructor to present content.

Morgan et al. (2002) have described an SVE called the Cave Collaborative Console (CCC) which included several features related to viewpoint that were specifically designed to allow instructors to guide learners through an environment. Users within the CCC were given a display menu which indicated the position of other users within the environment. Using this information, an instructor could quickly determine the position of all students within an environment at a glance. Within the CCC, an instructor could also quickly relocate within the environment to a location nearest a student. An instructor could control the point of view of a student within an SVE allowing the best observation point for a particular concept. By communicating through networked machines, an instructor and a student could work within the same SVE without viewing the same display device or being present in the same geographic location. This functionality allows SVEs to be leveraged as a communication tool in both distance learning and traditional classroom settings. The CCC also allowed the student to enter the point of view of the instructor or vice versa creating the opportunity for guided visual instruction of a concept. This control could also be extended in such a way that the instructor could digitally tether a group of students so that the group followed as the instructor led. Just as these tools can allow an instructor to guide students, SVEs can also allow students to guide one another as well.

As described by Roussos et al. (1999), SVEs can be used as a setting to promote social interaction and collaborative learning for students. Within the Narrative-based, Immersive, Constructionist/Collaborative Environments (NICE) Project, students were able to create objects within a stereographic virtual space together. The objects within the NICE SVE consisted of a garden in which students were able to virtually seed and tend to plants while learning to care for their growth. The virtual garden transformed based on the actions and interactions of the students tending them as well as to the programmed “natural” behaviors based on biological concepts. These behaviors caused the plants to react to elements within the environment such as virtual rain and sun as well as to the location of other plants such as weeds. Since each student user had the ability to harvest or plant within the collective garden, students learned how to cultivate and tend to the garden while also developing skills related to dealing with each other. The level of conceptual exploration and collaborative learning present in this environment make it a good example of the possibilities of an SVE as an instructional tool.

Integrating stereographic virtual environment technology into a traditional instructional setting is not, however, without its challenges. Johnson and Leigh (2002) have documented many of the challenges associated with integrating content in the form of virtual environments into a third grade classroom through the Quickworlds program. The study revealed the difficulties arising from using a large, immersive stereographic display in an elementary school. The researchers set up a system by which teachers could request instructional content in the form of virtual environments that suited the instructional needs of the teacher. Students assigned to the project at the University of Illinois at Chicago fulfilled this request. The content was then placed on the hardware, which in this case, was an Immersadesk, a display device which projects a stereographic computer-generated image. Unfortunately, despite this established pipeline of content from designer to display station, the project faced many logistical challenges. Johnson and Leigh (2002) have suggested that the delicate and expensive equipment involved in the display of stereographic virtual environments can create some difficulties in educational settings including the problems of insufficient resources such as time and manpower to be able to successfully integrate this type of content into the curriculum. Also technical support at the school was far below what would be needed to maintain such a system annually. In order to justify the resources needed to support such an endeavor, there needs to be evidence of SVEs effectiveness as learning tool. Despite this need, evaluation of stereographic virtual environments as instructional aids has been limited to a certain degree by the small number of research projects generally due to cost, complexity, and immature technological aspects within the field of virtual environment research (Cobb & Neale, 2002). However, several factors have emerged as important when examining evaluative studies related to the use of SVEs in education.

Evaluation of Stereographic Virtual Environments in Education

The evaluation process for stereographic virtual environments is difficult to simplify due to the inherent complexity of software applications designed to create three-dimensional models of environments. Evaluation of an SVE as a tool to promote learning involves examining factors related to both instructional design and usability engineering. Multisensory cues, motion sickness, user interaction, stereographic depth cues and learner characteristics are cited as important evaluative factors within a review of the research associated with stereographic virtual environments in education (Cobb & Neale, 2002; Salzman et al., 1999).

Multisensory Cues

Besides visual information, stereographic virtual environments can present additional multisensory cues. Audio signals for example can convey information to participants immersed within SVEs. For instance, Allison, Wills, Bowman, Wineman, and Hodges (1997) have described an SVE that contained both a narrative instructional audio track as well as audio signals which corresponded to the activity within the environment. The SVE was designed to educate users on the habits of gorillas in a zoo habitat. Audio cues, such as gorilla sounds, complimented visual information to create a more realistic representation of the environment inside the gorilla habitat. Project ScienceSpace, described by Salzman et al. (1999), also used auditory stimuli to provide additional information to learners. Sounds emitted through headphones within the Head Mounted Display worn by the learner indicated the magnitude and direction of particle movement within an SVE called NewtonWorld. The evaluative model for NewtonWorld consisted of not only audio cues, but also tactile cues contained within the SVEs.

The use of tactile cues within virtual environments is a specific area of research called haptics (Biggs & Srinivasan, 2002). Haptics can be used to describe the location or structural characteristics of an object within an SVE. Tactile information can be conveyed through numerous devices ranging from joysticks to exoskeletal gloves. The haptic device used in Project ScienceSpace, for instance, consisted of a vest that delivered vibrations to the user based on effect of the surrounding forces occurring in the SVE. Salzman et al. (1999) used the presence of these vibrations in concert with the audio signals to evaluate the effect of various multisensory cues on learner performance. The results of the study indicated that learners receiving these cues appeared more engaged than learners receiving visual cues alone. The combination of visual, auditory, and tactile cues created a complex stimulus evaluation that also included assessment of motion sickness as an evaluative factor for education.

Motion Sickness

Virtual environments have the capability to provide rich experiences for users that engage the senses and create illusions such as floating in space or teleporting from one place to another (Morgan, et al., 2002). The complexity of stimuli capable of being delivered within virtual environments can also pose problems as well. Throughout the field of virtual environment research, one barrier to the widespread use of virtual environments in practical applications such as education is the concern over motion sickness, sometimes also described as simulator sickness (Kennedy, Stanney, & Dunlap, 2000; So, Ho, & Lo, 2001; Cobb, Nichols, Ramsey, & Wilson, 1999).

Some symptoms of motion sickness include an emetic response, oculomotor disturbances (eyestrain), ataxia (postural instability) and vertigo (Kennedy et al., 2000; Lawson, & Graeber, 2002). Cobb et al. (1999) have suggested the roots of these symptoms appear to be within the conflict generated between signals by the "three major spatial senses: the visual system, the vestibular system, and novestibular proprioception" (p. 2). The visual system consists of the eyes and the nerves through which they are connected to the visual cortex of the brain. The vestibular system is located within the inner ear and acts as an aid to physical balance through monitoring air pressure and variations from a person's upright position. These components also exchange signals to determine body orientation by interpreting the orientation of the visual field.

Nonvestibular proprioception refers to the body's sense of where its components are relative to the body itself (Kalat, 1995). Proprioception is the body's sense of where parts of the body are relative to the rest of the body (Bakker, Werkhoven, & Passenier, 1999). One source of motion sickness is visual inertial conflict between the visual system and the vestibular and nonvestibular proprioception systems (Cobb et al., 1999; Harm, 2002). For example, if an individual is standing in a virtual environment and the room is virtually spinning but the floor and walls around the individual do not physically move, the eyes' interpretation of the event conflict with what the vestibular and nonvestibular proprioceptive conclude as non-movement (Cobb et al., 1999; So et al., 2001)

Technical factors within the display of virtual environments shown to contribute to a higher rate of motion sickness include slow refresh rate, poor resolution, motion platforms, discrete flickering, errors in tracking systems, optical distortion, and a slow rate of update between the display and the system's computing resources (Kennedy et al., 2000; Harm, 2002). Exposure duration is also typically listed as one of the most important factors that can influence the rate of simulator sickness (Kennedy et al., 2000; So et al., 2001; Harm, 2002). Motion sickness can also be reduced by limiting the amount of disturbance of the visual field through movement. The amount of movement made possible for a participant is also a component of the type of interaction within the SVE.

User Interaction

Technological developments in the field of virtual environments have generally outpaced progress in the methodology surrounding the design for interaction within them (Fencott, Van Schaik, Ling, & Shafiullah, 2003). Despite this rapid growth, a considerable amount of research surrounding interaction with virtual environments has been conducted simply because useful applications exist for virtual environments (Fencott et al., 2003). Many of the traditional design rules of research in human computer interaction do not apply to virtual environments because of the attributes unique to the field (Cobb & Neale, 2002; Bowman, Gabbard, & Hix, 2002). Standard methods of interacting with information that may make sense on a desktop computer do not always make sense within the three-dimensional space allowed by virtual environments (Bowman et al., 2002). Because there are so few accepted hardware interfaces that exist for creators and users of virtual environments, there remains a large niche for developing new interaction techniques. A tremendous number of input devices are available for use in three-dimensional virtual environments, and the number is still rising (Bowman et al., 1999; Fröhlich & RyaPlate, 2000). However, there is a distinction to be made here between interaction techniques and input devices.

Bowman, Kruijff, Laviola, and Poupyrev (2001) have described interaction techniques as ways the user is allowed to use an input device such as a mouse to make changes in the virtual environment. For example, a user utilizes an input device consisting of a pen and tablet in which the application is made aware of the location of the pen and tablet and accordingly interprets this as symbolic information. The device itself can be very useful in a situation such as with the use of a head-mounted display because the user can set it aside when he or she is not using it. It also has physical constraints that allow the user to employ two-dimensional interaction techniques while within a three-dimensional space. Within a single application, several interaction techniques could stem from the pen and tablet metaphor due to these properties. Within a map-based application, for example, two interaction techniques that could be used with the pen and tablet as a travel metaphor could be *pointing* or *dragging*. Pointing, consisting of moving the pen to a particular point at once, is often shown to be used to teleport to a new place on a map. Dragging, which is sweeping from one point to another on the map represented on the tablet, is used to travel quickly between two points. Choosing the appropriate interaction technique and evaluating performance accordingly is important in conducting research on user performance within a virtual environment. When evaluating interaction techniques, researchers have to analyze each action users make during those interactions. In a virtual environment, users have the opportunity to interact with the objects in front of them in a variety of ways. In terms of applications, the three important actions in an environment are *selection*, *manipulation*, and *navigation*.

Selection involves the user indicating to the system that he or she wishes to interact with a particular object or group of objects (Bowman et al., 2002). Selection is important within a virtual environment because the manner of selection often extends the user's reach beyond physical constraints. The ability to select an item within a virtual environment by pointing to the item, regardless of distance, could decrease the time it takes to accomplish tasks. However, inadvertently selecting incorrect objects could reduce efficiency. Methods of selection used in virtual environments range from the traditional left click to the use of auditory commands as menu selection tools. The best choice of selection method is generally dependent on the nature and intent of the virtual environment.

Manipulation involves changing the properties of the object itself such as color, shape, size, or other quality (Bowman et al., 2002). The hierarchy of subtasks that can be involved in selection and manipulation is immense, and it is variations within the components of various aspects of this hierarchy that define a particular interaction technique. For instance, it could be a difference in the method a user chooses to connect two fingers together that separates two interaction techniques. Researchers compare the complexities of each technique to establish effective ways of designing useable applications.

Navigation is the process by which users move from one part of a virtual environment to another (Bowman et al., 1999). Since users need to be able to move around in the virtual space in order to make full use of it designers should strive to provide navigation tasks that do not allow users to become disoriented in the three-dimensional space of a virtual environment (Bowman et al., 1999). For instance, collision detection can be used to prevent a user from walking into certain areas or, more importantly, to keep the user on a particular path. *Way-finding* is the process of determining the appropriate direction of travel to accomplish a task (Darken, Allard, & Achille, 1998). Within a large virtual environment, effective way-finding can be daunting (Darken et al., 1998). Studies have shown that placing cues within the environment can help users avoid becoming disoriented within large SVEs that demand intricate way-finding strategies (Darken et al., 1998)

The hardware used and its demands on the user can also influence navigation. Technologies such as tracking devices now enable researchers to give the computer generating the virtual environment constant updates as to position and orientation of the person within the environment (Welch, 2002). This tracking allows the application to generate the appropriate synthetic viewpoint to create the illusion that the user is seeing a view within the environment (Welch, 2002). Tracking can allow for interaction that could include the turn of a head to change a view (Freeman, Avons, Pearson, & Ijsselstein, 1999). Tracking devices allow the user to move as if within the physical world as they update the position in the virtual world. Through tracking a user's natural body movement can be interpreted as the movement within the virtual world. Indeed, the multitude of possible interaction techniques made possible by tracking a learner's movement represent a great deal of potential research opportunities. Several studies suggest that examination of stereographic cues as an evaluative factor is also a viable area of research.

Stereographic Cues

The presence of stereographic depth cues is examined as an evaluative factor throughout the literature. (Salzman et al., 1999; Trindade et al., 2002; Cartonnet, 1999). Trindade et al. (2002) have described comparing learners' behavior within stereographic and nonstereographic environments. The results of this descriptive study indicated that the presence of stereographic depth cues within the environment was relevant in recognizing certain aspects of crystalline structures. Salzman et al. (1999) have suggested that stereographic display be considered as a feature of VEs and investigated as it relates to other evaluative factors within the use of VEs as learning tools.

Cartonnet (1999) has also compared a stereographic presentation method with a two-dimensional presentation method. The study involved subjects receiving either a stereoscopic representation of a robotic arm or one of two representations of the same arm at different angles. The subjects were then asked a series of questions related to the structure and function of the arm. Subjects receiving the stereographic presentation performed twice as well as those in either of the two two-dimensional groups. This was especially notable because the phenomenon occurred regardless of the classification based upon prior professional experience. As this example demonstrates, classification based on learner differences can often reveal interesting relationships among evaluative factors for SVEs in education. Prior knowledge is a common measurement within research associated with instructional design. The notion that research related to SVEs would be more informed by addressing variability due to learner characteristics is supported in the literature surrounding both Human Computer Interaction (HCI) and Instructional Design.

Learner Characteristics

Corey (1971) specifies that in order to create effective instruction, "the relevant characteristics of the population to be instructed must be taken into account" (p. 12). This idea is indicative of many models for instructional design which suggest an analysis of learner characteristics during the design process (Dick, Carey, & Carey, 2004; Gagne, Briggs, & Wager, 1992). Within such learner analyses, designers evaluate the characteristics of learners relative to a range of areas including age, prior knowledge, or perceptual style. Variations among individuals are also the subject of research related to technology specific disciplines such as HCI.

Through an extensive review of the literature, Dillon and Watson (1996) investigated the relationship between research in HCI and parallel research in user differences from the fields of psychology, education, ergonomics, and others. Within the series of factors that the authors contend emerge from this review, there are several with specific application to SVEs:

1) There are basic differences in the abilities of users that have been identified through reliable and valid investigation
2) The influence of these differences can often be predicted and assessed based on the body of knowledge surrounding them
3) "This theoretical analysis of user differences would support greater generalization of findings across HCI applications. This would enable research to build on a scientific

> base and advance user classifications from their current reliance on experience or job-based criteria” (p. 632).

This approach favored by Dillon and Watson (1996) involves identifying established differences in user ability and the manner in which these differences could influence a specific task. These differences suggest the authors can impact the manner in which the user processes information and consequently influence the tasks the user is expected to carry out. As technology is used as a learning tool, these differences in the manner in which individuals perceive information will undoubtedly affect learning outcomes.

Moore, Burton, and Myers (1996) describe these differences in visual perception: “We assume that human sensation is about the same for all of us. When confronted with a visual stimulus, we assume that our rods, cones, optic nerves, and so forth react about the same. Perceptually, however, we do not *see* the same things. We extract (and create) meaning from visual stimuli just as we do from text. Therefore, our prior experience, inferences, expectations, beliefs, physical state, and other factors determine what we see as surely as the stimulus before us” (p. 982).

It stands to reason then that within a medium as visually complex as virtual environments, these differences in visual perception should be addressed. One aspect of HCI research related to perceptual differences and complex information technology such as virtual environments deals with the user’s ability to recognize and provide structure. Chen, Czerwinski, and Macredie (2000) have described this type of research as the investigation of the manner in which “individuals differ in their abilities to capture, recognize, and make effective use of abstract, implicit, and changing structures found across many large information systems and virtual environments" (p. 503). This pattern of structuring information is discussed within instructional design research as an individual's cognitive style.

Witkin et al., (1977a) have described cognitive styles as stable, consistent differences in "how individuals perceive, think, solve problems, learn, relate to others, etc." and which are pervasive throughout the aspects of an individual's life (p.15). Witkin and Goodenough (1981) have suggested that classification relative to these modes enhances the understanding of how individual differences are related. Investigation of cognitive styles and their relationship to specific tasks can reveal methods of accommodating learner differences through design. Ausburn and Ausburn (1978) have advised that "cognitive style is important as a learner characteristic relevant to instructional design because it influences the ability to process information or learning stimuli as required by a learning task; supplantation is important as an instructional design technique because it can bridge the gap between learner and task by assisting with the necessary processing" (p. 344). A cognitive style that may relate closely with stereographic virtual environments because of its close association with an individual's pattern of structure to complex visual information is the construct described in the literature as field-dependence-independence.

Field Dependence Independence

Background

Field dependence-independence (FDI) is a cognitive style often measured when examining an individuals ability to structure information around complex visual media (Witkin, Dyk et al. 1974). FDI originated out of research related to an individual's perception of the location of the upright position. Witkin (1949) found that individuals differ in the way in which they establish their position in the space around them based on visual information. Some individuals establish their position in space based mostly on the visual field around them and are therefore described as *field-dependent*. Other individuals judge their position based mostly on an internal frame of reference and are not influenced by the surrounding visual field. The individuals are described as *field-independent*.

Research in this area has shown that FDI is not characterized as a dichotomous classification (Witkin, Dyk et al. 1974). Instead, field dependent and field independent can be used to describe relative differences in the way an individual or group of individuals perceive the world around them. Therefore, the difference between individuals in FDI can be characterized in terms of degrees of difference. Relatively field dependent individuals (FDs) can be considered to rely more on the surrounding visual field for information than relatively field independent individuals (FIs). Since these descriptions of based on degrees of relative difference, there should not be misinterpretation as to the existence of two distinct types of people.

The degree to which an individual is influenced by the surrounding visual field can be seen by requiring the individual to perform tasks in which the field provides information that conflicts with internal stimuli such as sense of gravitational pull (Witkin 1949; Witkin, Dyk et al. 1974). In fact, the concept of FDI emerged from the observation of individuals performing tasks which required the subject to make judgments in which the surrounding visual field provided distracting stimuli. These tests included the Tilting Room - Tilting Chair Tests, the Rod and Frame Test, and the Embedded Figures test. Therefore a closer examination of these tests provides insight into their relationship to the overall concept of FDI.

The Tilting Room - Tilting Chair Tests (TRTC) involves an apparatus which includes a room that is capable of being tilted on a single axis to the left or right (Witkin, Dyk et al. 1974). Within this room, a chair is mounted in such a way that it can also be tilted on the same axis as the room but otherwise independent in its orientation to the room. The TRTC tests are made up of two parts, the room adjustment test (RAT) and the body adjustment test (BAT).

The RAT involves beginning the test with the room tilted at 56° and the chair tilted at 22° (Witkin, Dyk et al. 1974). The test consists of eight trials with half involving the room and chair be tilted to the same side and half involving the tilting of each to opposite sides. The procedure for each RAT trial requires the subject to instruct the examiner to rotate the room to a position which the subject perceives to be an upright 90°. The subject's chair does not move during the course of each RAT trial. The score for the RAT is based on the mean difference among the trials between the true upright position and the subject’s indication of the upright position through the orientation of the room.

In comparison, the BAT begins the test with the room tilted at 35° and the chair tilted at 22° (Witkin, Dyk et al. 1974). The BAT consists of six trials with half involving the room and chair be tilted to the same side and half involving the tilting of each to opposite sides. The BAT procedure does not involve moving the room during the trial in any way. Instead the subject controls the movement of the chair and tilts the chair itself to a position which the subject perceives to be upright. The score for the BAT is based on the mean difference among the trials between the true upright position and the subject’s indication of the upright position through the orientation of the chair.

Both the RAT and BAT assess the subject's perception of the upright (90° to the ground) position (Witkin, Dyk et al. 1974). Both tests involve requiring the subject to make this assessment despite a conflict between the true upright and the surrounding visual field. The level of influence this conflict has on each subject is revealed by the difference between the subject's perception of the upright and the true upright. A FD subject who is influenced by the tilted chair or the tilt of the surrounding room will report a perception of the upright that differs substantially from the true upright. A subject who judges the true upright correctly is not influenced by the tilt of the chair or the room is therefore FI. Since the difference between FDs and FIs is not a binary descriptor but rather a continuum which describes an individual's perception of the world around them in comparison to the perception of others, an individual's score is based on its relation to the scores of other individuals. For this reason, a subject's raw score on the RAT and BAT is converted to a standard score based on the relationship between the raw score and the mean for subjects of similar age and gender. Standard scores on series of subjects provide an indication of the differences among the population relative to FDI. These differences can be demonstrated further by examining another measurement of a subject's perception, the rod and frame test.

The rod and frame test (RFT) involves a luminous square frame, a luminous rod, and a chair for the subject to be seated within (Witkin, Dyk et al. 1974). Within this test each of these three items are mounted in such a way that they can be tilted on an axis within a darkened room. The darkness of the room permits the user to see only the rod and frame as visual stimuli. The subject is required to instruct the examiner to adjust the rod to the upright position while the frame and chair remain motionless.

The orientation of the subject's chair, the rod, and the frame are varied through three series of eight trials per series (Witkin, Dyk et al. 1974). The side which the frame is tilted to, either right or left, is alternated between each trial. In series one the subject's chair is tilted to either the left or right side at an angle of 28° and the frame is tilted to the same side also at an angle of 28°. The subject must instruct the examiner to adjust the rod to the upright position from a starting position of 28° either to the same side or to the opposite side as the frame. During series two, the process is the same except the subject's chair is tilted to the opposite side of the frame. In series three, the subject's chair is upright and the frame is tilted to the left or right. The score for each series consists of the mean absolute difference in degrees between the subject's assessments of the upright and the true upright (Witkin, Moore et al. 1977). As with the TRTC tests, this raw score is converted to a standard score based on the score's relationship to the mean and standard deviation of the scores of the subject's gender and age group. This mean score of the standard score for the three series, weighted equally, describes the subject as FD when high and FI as low. The RFT like the TRTC tests uses this score to categorize differences in the manner in which individuals orient themselves in space as FDI.

Consistently high correlations among the RFT and TRTC tests reinforced the idea that FDI was indeed a valid construct which characterized differences in individuals' perception of the surrounding world (Witkin & Goodenough, 1981). Witkin also determined that another aspect of the FDI construct involved the degree of difficulty to which an individual has trouble identifying an object within a complex surrounding visual field. The aspect of FDI can be further explored by examining another perceptual test which shows high correlation with the RFT and TRTC: the Embedded Figures Test.

The Embedded Figures Test (EFT) differs from the TRTC and RFT tests in that it does not involve changes in body position or orientation toward the upright. Instead the EFT involves a procedure which requires the subject to separate a simple figure from the surrounding complex background. The EFT consists of twenty-four complex visuals that each contain a simple figure hidden within the surrounding patterns.

(Witkin, Moore et al. 1977a) demonstrates how the EFT parallels the RFT and the BAT since "the subject is presented with an item, now a simple geometric design rather than a rod or a body, which is contained within a complex organized field, now a complex design rather than a frame or a room, and once more what is at issue is the extent to which the surrounding visual framework dominates perception of the item within it" (p. 6). The subject is given a maximum of five minutes to find each hidden figure. The subject's raw score is calculated as the mean amount of time taken to find the simple figures within the complex backgrounds. In the same manner as the BAT and the RFT, the raw score is converted into a standard score that reflects the relationship between each subject's score and the scores of the same gender and age group (Witkin, Dyk et al. 1974).

A similar pattern emerges with the EFT as compared with the other perceptual tests (Witkin, Moore et al. 1977a). Some individuals have no difficulty extracting the simple geometric figure right away from the complex visual field surrounding it. Some subjects take longer to find the figure and others can not complete the task at all.

As predicted, there is evidence that the same subjects who are most heavily influenced by the visual field in the BAT and the RFT are the same subjects who are so strongly influenced by the complex visual field in the EFT that they have difficulty (Witkin, Dyk et al. 1974; Witkin, Moore et al. 1977a). The stability of an individual's level of FDI over time has been examined often and results indicate that individual does remain consistent in their mode of perception (Witkin, Goodenough et al. 1967; Witkin, Dyk et al. 1974). This consistency has made possible the investigation of the distribution of FDI within the population and of the impact that the construct has beyond the realm of visual perception.

The importance of FDI as a factor in perceptual research is based on the idea that FDI is a stable measurable characteristic that extends in applicability beyond visual perception and into domains of intellectual and social activity (Witkin, & Goodenough, 1981). For instance, an individuals level of FDI, can influence the way in which an individual interacts with people around them. Since FIs recognize more of a separation between themselves and the stimuli of the world around them, it would seem logical that FIs would be more concerned with the needs and feelings which they experience as their own rather than those of the people around them. FDs in contrast experience very little separation between self and non-self and therefore have more involvement with the outside world. Research has shown that FDs tend to be more likely to seek out the company of others than FIs (Witkin, & Goodenough, 1981). This area of research has shown that the FDI construct influences other aspects of an individual's life and the lives of those around them. Understanding the impact of FDI on other aspects of human interaction requires an awareness of the trends which exist in the distribution of FDI.

Research related to FDI and age reveals significant trends throughout the human lifespan. Measurements of FDI that are specifically designed for younger subjects such as the Children's Group Embedded Figures Test indicate that children tend to be more FD than adults (Amador-Campos, & Kirchner-Nebot, 2001). Older adults tend to be more FD than middle-age adults as well (Hagberg, Samuelsson, Lindberg, & Dehlin, 1991). When examining older populations such as those aged sixty five and above, factors such as health status and visual ability could potentially influence the level of FDI found. However, some research in this area suggests that older adults tend to be more field-dependent even after controlling for these factors.

There are also trends of FDI related to gender. Overall, the majority of research suggests that males tend to be slightly more field-independent than females (Witkin, et al. 1977a; Witkin, et al. 1977b). There is research from cross-cultural examinations that suggests that this finding may be linked with societal roles. For instance, in cultures in which the woman's role differs little from the man, there is less recorded difference in level of FDI between the sexes. Within these cross-cultural studies, the question of whether the occupational role influences the level of FDI is not clearly resolved. However, the relationship between FDI and outcomes within education and occupation has been the source of a great deal of research.

Educational Implications

In a review of literature regarding the educational implications of FDI, (Witkin, et al. 1977a) notes that the construct does not prove to be a predictor of overall academic performance. The impact of FDI instead manifests itself in the instructional situation in which relatively field-dependent or field-independent learners have comparable success or difficulty. Field-independent individuals seem to perform better in the natural sciences and mathematics. Field-dependent individuals performed better in disciplines such as psychology, nursing, elementary education. A more recent assessment of the literature by Tinajero and Paramo (1997) has suggested however that FIs outperform FDs regardless of academic subject. Regardless, there is evidence that the cognitive style FDI impacts a learners ability to perform academically. The distinction between FDs and FIs can be identified by examining the manner used to process the stimuli around them.

Field-dependent and field-independent individuals differ in the way in which they provide structure to information. Kiewra and Frank (1985) found that FDs perform better in situations where structure is provided in the organization of the material. This is congruent with Witkin (1981)'s assessment that FIs analytically bring their own structure to material whereas FDs somewhat passively depend upon the structure around them to make sense of information.

Rickards, et. al., (1997) investigated an instructional strategy intended to assist FDs in establishing structure around information. Subjects within the treatment group were instructed to take notes related to the instructional material being presented. The control group was given no such instructions. The results indicated that the notetaking strategy influenced the performance of the FDs more than the FIs. The strategy of compelling the subjects to take notes allowed the FDs to establish the level of structure for the instructional content that FIs develop without any intervention.

While providing structure aides FDs, the presence of a high level of visual complexity inhibits their ability to gain information from the materials. The same impact of the surrounding visual field that is demonstrated through the Embedded Figures Test also manifests itself as individual processes information from a visual.

"Field dependent individuals, when presented a visualized presentation tend to modify the structure but accept and interact with it as it is presented. They tend to fuse all segments within the visual field and do not view or interact with the visual components discretely. Field independents tend to act upon a visual stimulus, analyzing it when it is organized and providing their own structure when it lacks organization" (Dwyer & Moore, 2001, p.310).

FDs are more likely then to have difficulty separating the information associated with specific visual elements of instruction from the surrounding elements of the presentation. By contrast, FIs do not demonstrate difficulty with complex visual media. The influence of these relatively different manners of processing information has provided a challenge for instructional designers working with visual media.

Media and Field Dependence-Independence

FDI has been a variable addressed in numerous research studies which investigate elements of effective instruction. The intent is to identify visual media elements such as text, color, or level of realism which may assist FDs in disembedding information from the surrounding visual field. The influence of these elements depends upon whether they provide salient cues for the FDs to improve their performance or conversely serve to make the visual field too complex. Witkin (1976) suggests that FDs tend to be influenced by the most salient cues within a visual whereas FIs gather information throughout the visual. Research associated with FDI and visual media has focused on providing salient cues to enable FDs to gain information more effectively.

Dansereau (1982) examined the effectiveness of utilizing text as a means of directing attention to important components of instruction. One group received materials with text-based instructions without text-based headings while a second group received text-based headings without any instructions. A third treatment group received both headings and instructions. While the results indicated that overall, learners performed better with both headings and instructions, FDs were unable to perform at the level of FIs regardless of assignment to treatment group indicating that this text-based approach was sufficient to assist FDs in developing structure.

Thompson and Thompson (1987) investigated the effectiveness of using text-based organizers such as headings within instructional materials for learners of various levels of FDI. The treatment group received written instruction with text-based headings on the center and the left of the materials. The control group received materials with no such headings. FDs within the treatment group performed better than FDs in the control group. The authors suggest that the text based headings allow the FD learners to provide structure to the material.

In extensive review of the literature surrounding use of illustrations as instructional materials, Dwyer (1978) suggests that color be considered an important instructional variable capable of communicating information to the learner. Color can be used within instruction to provide a color-coding scheme that provides additional cues for learners (Dwyer & Moore, 1992; Dwyer & Moore, 2001). “Color coding may be considered a strategy which students enhance or sharpen essential message characteristics by providing structures for the storage of new information” (Dwyer & Moore, 1991/1992, p.312). Dwyer and Moore (1991/1992) examined the effectiveness of color-coding in enhancing instruction for learners of various levels of FDI. The intent was to determine if color-coding would provide a salient cue for field-dependent learners to generate structure around. The study utilized a set of instructional materials related to the heart and a set of accompanying tests of visual recall which have been utilized throughout research associated with visual literacy (Dwyer, 1978). The scores of these tests for subjects receiving black and white materials indicated that FIs significantly outperformed FDs within this group.

Within the group receiving color-coded materials however, no significant difference existed between FDs and FIs. These results suggest that the color-coding allowed FDs to better extract information from the instruction and thus perform at comparable level to FIs who extracted the information regardless of color. Another study Benbasat and Dexter (1985) also found that FDs given color-coded materials significantly outperformed FDs given black and white materials.

While Dwyer and Moore (1991/1992) and Benbasat and Dexter (1985) compared treatments with black and white images to treatments with full color images, Worley and Moore (2001) assessed the effectiveness of highlight color. Highlight color in this case was defined as color used within predominately black and white materials. The four treatments consisted of one with full color images, a second with highlight color using realistic colors, a third with highlight color using a single yellow hue, and a fourth as control with only black and white images. Worley and Moore (2001) found that FIs outperformed FDs overall and in every treatment group including the control. This study suggests that highlight color does not serve as a sufficient cue for FDs to provide structure to information and is indicative of the difficulties associated with attempting to provide salient cues for FDs to gather information.

Without cues to form structure around the information, FDs generally do not perform at the same level as FIs on tasks associated with visual learning. This raises the question of whether there may be some way to design interactive visuals that inherently provide structure through their organization and ability to give the user control. This approach to designing for differences in FDI by providing structure through interactivity has been explored within the instructional design literature associated with the area described as *hypermedia*.

Interactive instructional media, often referred to as hypermedia, allows the learner to access the components of the instruction through selecting the specific components the learner is interested in seeing (Moore, Burton, & Myers, 1996). Hypermedia can be organized in a variety of ways which have the potential to assist an individual in developing structure around content and has therefore been a source of research related to FDI. Because of the complexity of instructional content such as hypermedia, it is important to examine specific variables within the medium such as learner control, organization of search tools, or presence of motion within the content.

The amount of control that the learner has in varying the content of the interactive instruction is a variable which can be influenced by cognitive style. Yoon (1994) examined this variables relationship to FDI by providing instructional media treatments with three levels of control. The first variation in treatment, denoted as *program control*, involved "a predetermined sequence of instruction organized in a hierarchical structure" (p.357). The second variation denoted as *learner control* allowed the user to move through any part of the instruction without any predetermined restraints. The third variation denoted as *learner control with advisement* allowed the same level of user control but provided feedback relative to the order of the instructional components accessed. FDs receiving program control completed the instruction significantly faster than FDs with either learner control or learner control with advisement. FIs completed the program at roughly the same speed regardless of assignment to treatment group. In examining performance however, treatment type made a difference for both FDs and FIs.

According to Yoon (1994), "The findings support the argument that when students with field dependence are provided program control and learner control with advisement instead of learner control, they can enhance their learning" (p.365). Another aspect of interactive media which has been investigated as a means of accommodating FDs is the organization of search capabilities within the materials.

Leader and Klein (1996) examined the effect of FDI on the use of different search tool designs within hypermedia databases. An instructional database, Earthquest, contained information presented using text, graphics, animation, and sound. The database also contained three tools designed to allow users to search through the material: *browser*; *index/find*; and *map*. The browser tool consisted of icons within the material used to connect to another component of the instruction. The index/find tool provided a text-based list of topics within the materials. The map tool was used to "display a hierarchical arrangement of the content and allow searching by section, subsection, and individual screen topic" (p. 8). Within three of the four treatments, all but one of the tools was disabled in order to isolate and examine the effectiveness of each tool. The fourth treatment allowed users to utilize all three search tools. Following exposure to the appropriate treatment, learners of various levels of FDI were then assessed using a posttest related to the content. FIs significantly outperformed FDs in this study overall. An interaction was also found between type of search tool provided and cognitive style. FIs significantly outscored FDs when using the index/find tool alone and when using the map tool alone. However, within the treatments which allowed access to the browser tool, browser alone and complete version, FIs did not significantly differ from FDs. This suggests that the browser-based icons within these two treatments provided salient cues that allowed FDs to provide structure to the information in the same way that FIs provide it on their own.

Another variable to examine within interactive content is the amount of motion among visual elements within the materials. Ghinea and Chen (2003) examined the impact of FDI on dynamic media content and its capacity to convey information. The authors defined dynamism as the rate of change in visuals among frames in the multimedia clip and included wide range of motion levels among the treatments including a relatively static news clip to a relatively dynamic rugby clip. The results indicated that the level of dynamic change within the content significantly impacted the learners' ability to gain understanding of the information presented. While FDs performed lower than FIs in every instance, no significant interaction was found between level of FDI and degree of dynamism in the content. This study provided an assessment of the manner in which learners of various levels of FDI may interact with dynamic visual content. The authors also suggest that similar investigation of interactive three-dimensional media such as virtual environments as a logical progression within this area of research.

Ogle (2002) examined the relationship between effectiveness of a virtual environment as a learning tool and differences in FDI among learners. The instructional materials, which were utilized by Dwyer and Moore (1992) as two dimensional booklets, were related to the structure and function of the heart and were modified into three-dimensional virtual environments capable of being presented using traditional desktop computers. Differing levels of FDI were used to compare the visual recall scores related to the heart materials. The results indicated that although FIs performed better in the virtual environment condition, no significant difference was found related to FDs. Since the virtual environments used within this study were displayed through nonstereographic devices, there is potential to reexamine field dependence within the context of stereographic virtual environments.

Research in the areas of neurophysiology, psychology, and HCI suggest a possible link between field dependence and stereopsis, the perceptual process initiated by stereographic displays. Although many nuances of the brain's mechanism for processing depth remain in question, many of the same processes involved in depth perception are also involved in separating a figure from its background (DeAnglis, Cumming, & Newsome, 1998; Deanglis, 2000). Therefore these processes would also be involved in the process of separating an object from its surrounding visual field. Arthur, Booth, and Ware (1993) investigated the performance of subjects in a tracing task which required the subject to outline the edges of an image. The results indicated that when images were presented stereographically, subjects tended to complete the task more accurately and more quickly that when images were presented in a nonstereographic manner. Stereographic depth cues have also been shown to allow viewers to break traditional illusions and recognize the shapes of objects more clearly (Coren & Girgus, 1978). These relationships suggest that field dependence may be a noteworthy evaluative factor in evaluating the effectiveness of stereographic virtual environments as learning tools.

Summary of Relevant Findings

Stereographic virtual environments allow researchers, engineers, and designers to express complex data within three-dimensional space (Gobbetti et al., 1999; Hernandez, et al., 1998; Nesbitt, Gallimore, & Orenstein, 1999). SVEs can be used in instruction to demonstrate ideas, explore concepts, and guide understanding. The considerable resources often associated with SVEs necessitate evaluation as to their effectiveness as instructional tools (Keefe, Acevedo, Moscovich, Laidlaw, & LaViola, 2001; Morgan, Kriz, Howard, das Neves, & Kelso, 2002; Roussos et al., 1999). Evaluative factors within SVEs include multisensory cues, simulator sickness, user interaction, stereographic depth cues and learner characteristics (Cobb & Neale, 2002; Salzman et al., 1999). FDI is a measurable learner characteristic which may impact the effectiveness of SVEs due to the level of visual complexity associated with this medium. There is also reason to believe that use of SVEs may create salient cues for FDs to create structure around (Arnold, Pettifer, & West, 2002).

Stereographic depth cues allow users to separate objects from the surrounding scene based on differences within the images on the left and right eye (Davis & Hodges, 1997). Stereographic displays create these cues as a means of communicating information to the user. Field-dependent learners have difficulty with visual tasks because of their inability to isolate information from a surrounding visual field (Witkin et al. 1977a). These factors suggest the need to examine the relationship between stereographic depth cues within virtual environments and field dependence.

In order to isolate the influence that FDI may have in using SVEs as learning tools, a comparison of the research literature surrounding each concept is necessary. All extraneous variables which may assist or hinder FDs or FIs should be eliminated or reduced as much as possible. In order to prevent variance due to the presence of multisensory cues for example, the SVE should not contain any audio, tactile, or olfactory cues (Salzman, et al., 1999). The effect of equilibrium disturbance and associated simulator sickness can also be reduced by limiting drastic changes in visual field and avoiding any unnecessary motion by the user (So, Ho, & Lo, 2001).

This can be further accomplished by addressing the way in which the subject will interact with the SVE.

Research surrounding SVEs has suggested that interaction within virtual environments such as the manner in which the user selects, manipulates, and navigates an environment can introduce variability into the set of conditions (Bowman, Kruijff et al. 2001). Likewise, research related to the degree and type of control given within interactive media can impact the performance of FDs (Leader & Klein, 1996; Yoon, 1994). Limitation of this variability due to type of interaction can be achieved through several avenues. One approach is to provide the subject with instructions that outline appropriate behavior within the virtual environment. A more rigorous approach is to in addition to the instructions, place functional limits on the constraints of the virtual environment and associated interface. Although this approach limits the complexity of the virtual environment, the result is a more controlled environment to isolate variables for study, which allows the user to exhibit only behavior consistent with the desired interaction technique. Since the method of interaction is determined largely by the type of hardware utilized, the type of stereographic display and input device are important factors in designing an effective research study.

Another method of limiting variability is to employ a desktop configuration which provides a more simple and familiar interface for all subjects. Based on the literature, a relatively simple SVE can be projected to a single subject through a desktop system utilizing autostereoscopic display (Sharp Laboratories, 2003). The Sharp system also contains a traditional keyboard-based input device which permits the design of a more conventional interaction technique for this SVE. This hardware configuration consisting of an autostereoscopic display and traditional keyboard input provides a platform to identify software considerations.

In order to determine the effectiveness of an SVE as a learning tool, the content presented within the instructional materials must not introduce another source of variability. The Dwyer heart materials and accompanying assessments have been used in a variety of studies related to visual literacy and the investigation of specific media attributes (Dwyer, 1978, Worley & Moore, 2001; Ogle, 2002; Dwyer & Moore, 1992). These materials are capable of being modified into virtual environments and provide an established source of content from which to construct an SVE.

The software considerations associated with the design of the SVE center around the manner in which to provide the intended stereographic depth cues without creating a visual environment that is too complex for FDs. Each section of the Dwyer (1978) materials discusses a specific structure or process associated with the heart. Although it is possible to embed depth cues within every aspect of the visual at all times throughout the instruction, doing so may cause FDs to be distracted by visual cues which are not relevant to the component. An alternative strategy is to embed depth cues within only the aspects of the visual being discussed by the text on screen at the time. Worley and Moore (2001) utilized color in the same manner to make salient only the portions of the illustration which the instructional materials are describing. Based on this approach, the tests of visual recall which correspond to the instructional materials should be modified to reflect the same visual style as the materials themselves. The test of recall for this study, the Modified Total Criterion Test (MTCT), will contain no stereographic depth cues as this would make standardization among treatment groups impossible.

Research suggests that field-independent learners should outperform field-dependent learners on tasks of visual recall (Dwyer & Moore, 1992; Ogle, 2002; Thompson & Thompson, 1987). It is conceivable that field-dependent learners will be aided in their perception of figures within an instructional stereographic virtual environment by the additional organizing information provided by stereographic depth cues (Coren & Girgus, 1978; Arthur, Booth, & Ware 1993). It is also plausible that learners who receive stereographic depth cues will outperform those who do not based on the presence of effective organizing information. The importance of this study is based on the fact that FDI represents a potentially important evaluative variable within research associated with SVEs and has not been addressed in previous research related to stereographic depth cues.

The central question that surfaces from the review of literature is whether the presence of stereographic depth cues will allow field-dependent learners to disembed visual information more efficiently. The display of stereographic materials within this study will use controlled virtual environments that contain information relative to depth. The usefulness of this depth information will be investigated relative to level of visual recall.

Research Questions and Hypotheses

To investigate the effect of stereographic virtual environments on recall among learners of different levels of field dependence, the following research questions have been proposed:

1) Does the presence of stereographic depth cues have any effect on the ability to recall information from a visual?
2) Does level of field dependence have any effect on participant's ability to recall information from a visual with or without stereographic depth cues?

3) Does the presence of stereographic depth cues have any effect on a field-dependent participant's ability to recall information from a visual?

An experimental design was used to investigate the proposed research questions and test the following hypotheses.

H_1 Subjects who viewed stereographic materials will score higher on tests of visual recall than subjects who viewed nonstereographic materials.

H_2 Field-independent learners will score higher on tests of visual recall than field-dependent learners regardless of assignment to stereographic or nonstereographic treatment.

H_3 Field-dependent learners who viewed stereographic materials will score higher on tests of visual recall than field-dependent participants who viewed nonstereographic materials.

The following chapter outlines the methodology for answering these research questions.

CHAPTER 2: METHODOLOGY

This chapter describes the approach and procedures utilized to answer the research questions in this study. This chapter includes a description of the experimental design, procedure, participant sample, test instruments, and means of analysis. As this research includes the use of human subjects, proper protocols relative to the use of human subjects have been strictly followed. Instruments used in this study were chosen to effectively isolate level of field dependence as an independent variable and level of visual recall as a dependent variable. Subjects for this study were chosen based on literature associated with cognitive style.

Participants

The sample for this study consisted of 48 females and 61 male adults between the ages of 18 and 45. Approval was obtained for research involving human subjects for this study (See Appendix F). These subjects were recruited at education centers throughout the Commonwealth of Virginia which provide education and training to adults. The subjects ranged in educational level from those attending Graduate Equivalency Diploma coursework to community college students within their first year of coursework. Permission was obtained from the Virginia Department of Education: Office of Adult Education. Individuals were selected based on age, willingness to participate, and lack of prior knowledge in subject domain related to the heart materials. Participants were screened through a two-question interview which addressed any employment history related to the medical field or any education within a similar heart related field such as a recent anatomy physiology courses. Prior knowledge within this domain would have influenced the results due to the fact that the instrument used to assess visual recall is based in this domain. Four females and two males were excused from the study due to prior knowledge through experience within occupation or education related to the heart. A total of 44 females and 59 males went on to complete all of the components of the test.

Instruments

The Group Embedded Figures Test (GEFT), a tool prevalent in a significant portion of research surrounding cognitive styles, is an efficient and effective method for determining level of field dependence (Witkin et al., 1971; Couch & Moore, 1992; Worley & Moore, 2001; Ogle, 2002). The GEFT is used to identify the degree to which an individual is influenced by the surrounding visual field. The subject is required to trace in pencil a simple figure which is hidden within a more complex visual based upon overlapping lines and shading The GEFT consists of 25 questions broken into three, timed intervals of one two-minute interval and two five-minute intervals (Witkin et al., 1971). The timed aspect of the test is to ensure that the individual's first reactions to the visual are captured. For each item within the test, a subject is instructed to identify and trace a simple shape embedded within a complex visual. For each item, there is a complex visual and a letter which corresponds to a simple figure on the back of the GEFT booklet. The figures on the back of the booklet are arranged in such a way that a subject cannot see both the complex visual and the simple figure at the same time. The subjects are instructed that they may look back at the simple figures as necessary in order to identify where the simple figure is hidden within the complex visual. Each subject is also made aware that the simple figure is always present within the complex visual provided for each item. Although the simple figure may appear more than once, the subject is only required to trace the simple figure once. The subjects are made aware that they can erase if they feel they made a mistake. If a subject traces the simple figure without being inhibited by the surrounding field, the item is scored as correct. If a subject traces the wrong figure, traces outside the lines of the correct figure or if a person omits an item, it is scored as incorrect. With 18 items, the test generates a score from 0-18, with a lower value indicating field dependence and a higher value indicating field independence. A third value, field neutral, is represented by a mid range score. Field dependent, field independent, and field neutral descriptors should be considered as areas on a continuum rather than distinct values. Witkin et al. (1971) reported the reliability for the GEFT at .82. Scores on the GEFT were used to classify subjects relative to level of field dependence based upon a method consistent with previous research by Dwyer and Moore (1992), Worley and Moore (2001), and Ogle (2002). Subjects scoring one-half standard deviation below the mean score for the GEFT were classified as field dependent. Subjects scoring one-half standard deviation above the mean score for the GEFT were classified as field-independent. Students within one-half standard deviation above or below the mean were classified as field-neutral.

The instructional materials consisted of a digital graphical presentation which could be navigated by a simple interface that allowed the user to move forward and backward through the presentation with minimal interference. The instruction was based on a unit of study developed by Dr. Francis M. Dwyer, including 2000 words of instruction (Dwyer, 1978). This instructional material which discusses the structure and function of the heart was modified with permission given by Dr. Dwyer in October, 2003. The materials used within this study were based upon the original Dwyer (1978) instructional materials. The images and text of the original materials were inserted into two separate digital PowerPoint presentations with one for the control group and one for the treatment group. The materials for the control group were not modified any further. The materials for the treatment group were modified using Tridef PowerPoint Plugin and Adobe

Photoshop. The modifications included the conversion to digital format and the addition of depth information needed to project components of the instruction stereographically (Appendix A). The Stereographic Equipment Verification, which consisted of five digital pages, was added to the beginning of the 21-page set of instructions in order to verify that each subject received the appropriate level of treatment (Appendix B). The SEV presented subjects with either a stereographic or nonstereographic image and instructed the subject to label on the answer sheet whether any depth existed on the screen. Subjects within the group receiving stereographic materials should have reported depth and subjects within the group receiving nonstereographic materials should have reported none. Three participants were eliminated from analysis based on scores on these questions inconsistent with assignment to treatment group. The instructional materials within Appendix A differed relative to the treatment group only in the presence or absence of stereographic materials. The computer configuration for the display of these materials remained constant, regardless of assignment to treatment group. The digital presentation was accessed from the hard drive of the autostereoscopic computers used in the study.

The instrument used to determine degree of visual recall was the Criterion Test, which corresponds to the instructional materials developed by Dwyer (1978). This test measures understanding of terminology related to the concepts of the heart's processes, the specific parts of the heart, as well as to the functioning of the heart during the systolic and diastolic phases (Dwyer, 1978). The Kuder-Richardson Reliability coefficient of .92 was computed for the Total Criterion Test from a random sampling of prior studies (Dwyer, 1978). The Dwyer (1978) test can be considered an instrument of four parts: identification, terminology, drawing, and comprehension. The identification and terminology tests are parts which, based on previous research, can be used effectively to determine the usefulness of a media attribute with respect to field-dependent learners and were used as the criterion for this experiment (Dwyer & Moore, 1992; Worley & Moore, 2001; Ogle, 2002).

The Identification test (Appendix C) was used to assess the subject's ability to identify the parts of the heart as a result of being exposed to the instructional materials. This test consists of 20 multiple-choice questions which correspond to numbered parts on a drawing of the heart. All subjects received the same version of the Identification test, regardless of assignment to treatment group.

The Terminology test (Appendix D) was used to assess the subject's ability to demonstrate knowledge of the definitions of terms related to the instructional materials. This test consisted of 20 multiple-choice questions related to basic concepts discussed in the instructional materials. All subjects received the same version of the Terminology test, regardless of assignment to treatment group. The scores of the Terminology test were then combined with the scores of the Identification test to create a total score, the Modified Total Criterion Test (MTCT).

Procedures

This study was conducted during Spring of 2005 at adult education learning centers in the Commonwealth of Virginia within the communities of Dumfries, South Boston, Fairfax, and Norfolk. These learning centers serve adult students who range from those who are attending high school equivalency classes to those who are attending community college classes. The order of all events related to the experimental procedure including all verbal and written direction was predetermined and standardized. This ensured that all subjects received exactly the same directions. Individuals who agreed to participate were first administered the consent form which outlines the nature of the study and type of compensation available. Next, subjects were asked whether they currently had any uncorrected vision problems and whether they had any prior knowledge related to the structure and function of the heart. Subjects who answered yes to either of these questions were politely dismissed with full compensation. Next, subjects were assessed as to level of field dependence using the Group Embedded Figures Test (GEFT). This timed test was conducted in accordance with the instructions and proctor script specified by the manual which accompanies the test. The GEFT answer sheets were prenumbered based on a codebook which allowed matching of individual data without gathering further personal information. A random number generator was used to ensure random assignment to treatment group for each subject.

After completing the GEFT, participants were escorted to autostereoscopic workstations as described in Sharp (2003) preconfigured for either stereographic or nonstereographic materials based upon the assignment to treatment group.

At this point participants were instructed from the welcome screen to begin the presentation which contained several questions concerning demographic information and equipment verification measures. These questions were followed by a screen which instructed the participant to mark the time and begin the modified instructional materials. The participants were also prompted to mark the time before beginning the testing portion of the materials. Time limits were not established for either the instructional materials or the testing portion in accordance with previous research procedures within studies related to field dependence and visual recall (Worley & Moore, 2001; Dwyer & Moore, 2001). Subjects were allowed to leave following completion of these tests and thanked for their participation.

Data Analysis

Scores of 103 participants were obtained for the Group Embedded Figures Test (GEFT) and the Modified Total Criterion Test (MTCT). Three of the participants, two females and one male, provided incorrect answers on the item that dealt with verification of assignment to treatment group. These three participants were all assigned to the treatment group and were therefore exposed to stereographic stimuli during the Stereographic Equipment Verification (SEV) segment of the materials shown in Appendix B. However, these three did not indicate that they received stereographic materials on their answer sheet and therefore the proper functioning of the stereographic aspect of the materials could not be confirmed. Consequently, these three subjects were eliminated from analysis. The group used in the analysis consisted of 42 females and 58 males for a total of 100 subjects within the analysis. The GEFT scores for each subject were used to trichotomize the group into field independent, field neutral, and field dependent. These three categories were then separated by the value indicating assignment to treatment group and therein representing level of stereographic depth cues. Performance on the Identification and Terminology tests were combined into the Modified Total Criterion Test (MTCT) were used to describe performance relative to visual recall of material from the instruction. A factorial analysis of variance was used to compare means of visual recall based on assignment to treatment group and category of field-dependence-independence. Analysis also determined the existence of any interaction effects.

Experimental Design

This study employed a 3 X 2 experimental post-test only design to determine main effects for the three levels of field dependence and the two levels of stereopsis as well as any interaction effects between the two variables (See Figure 1). The three levels for the variable of field dependence were *field-dependent, field-independent*, and *field neutral*. The two levels for stereopsis were *present* or *absent*.

Figure 1. Experimental design

	Field Dependence		
	Field dependent	Field neutral	Field independent
Stereographic depth cues absent			
Stereographic depth cues present			

CHAPTER 3: RESULTS AND DISCUSSION

This chapter reports the results of the study and the discussion of these results. Results such as mean overall test scores and the products of factorial analysis of variance are presented. The results are followed by a discussion of the findings as they relate to each research hypothesis.

The purpose of this study was to determine the effect of visuals that contain stereographic cues as compared to visuals without stereographic cues on the recall of participants of varying levels of field dependence. Based upon the review of literature surrounding field dependence and stereographic virtual environments, the following research questions were proposed related to the use of stereographic virtual environments.

1) Does the presence of stereographic depth cues have any effect on the ability to recall information from a visual?
2) Does level of field dependence have any effect on participant's ability to recall information from a visual with or without stereographic depth cues?
3) Does the presence of stereographic depth cues have any effect on a field-dependent participant's ability to recall information from a visual?

The procedure used in this study required participants to first complete the Group Embedded Figures Test (GEFT) which is a measure of each participant's level of field dependence. The GEFT generates a whole integer individual score between zero and 18 based upon each participant's answers to the 18-item instrument. Following the completion of the GEFT, each participant viewed a set of instructional materials in the form of a digital presentation as seen in Appendix A that described the parts and function of the human heart. Each participant then completed the Modified Total Criterion Test (MTCT) which is an assessment of a subject's recall of the instructional materials. The MTCT, consisted of two subcomponents, the 20-item Identification subcomponent and the 20-item Terminology subcomponent.

Results

As an analysis strategy to examine the impact of field-dependence and stereographic depth cues on visual recall, scores on the Group Embedded Figures Test were trichotomized based a procedure commonly used within this area of research (Dwyer & Moore, 1992; Worley & Moore, 2001; Ogle, 2002). Trichotomization based on level of field dependence/independence was accomplished by defining participants as field-dependent when generating a score which was one-half of a standard deviation less than the mean, defining participants as field-independent when generating a score that was greater than one-half of a standard deviation higher than the mean, and defining participants as field-neutral (X) when generating a score differing less than one-half of a standard deviation from the mean, $(M_x - .5\ S_x) < X < (M_x + .5\ S_x)$. This procedure resulted in a classification system in which participants with GEFT scores of 0-2.94 were defined as field-dependent, scores of 2.95-7.75 were defined as field-neutral, and scores of 7.75-18 were defined as field-independent. All of the 100 participants completed both the GEFT and both subcomponents of the MTCT. The scores of the Identification subcomponent, the Terminology subcomponent, and the MTCT are listed in Tables 1, 2, and 3. The data for each participant is listed in Appendix E.

Table 1
Means and Standard Deviations ( ) of the Identification Scores

	Nonstereographic	Stereographic
Field Independent	4.88 (1.96)	6.47 (2.61)
Field Neutral	4.29 (1.64)	5.41 (1.37)
Field Dependent	5.11 (2.02)	4.28 (1.56)

Table 2
Means and Standard Deviations ( ) of the Terminology Scores

	Nonstereographic	Stereographic
Field Independent	5.59 (1.42)	6.13 (1.60)
Field Neutral	4.86 (2.28)	5.41 (1.58)
Field Dependent	4.11 (2.18)	3.72 (2.05)

Table 3
Means and Standard Deviations ( ) of Modified Total Criterion Test Scores

	Treatment	
Cognitive Style	Nonstereographic	Stereographic
Field Independent	10.47 (2.60)	12.60 (3.16)
Field Neutral	9.14 (2.12)	9.53 (2.35)
Field Dependent	9.21 (1.90)	8.00 (1.53)

The mean score for the GEFT for this study (M = 5.35, SD = 4.82) was considerably lower than the means for other studies within this research area such as Worley and Moore

(2001) which recorded a mean of 11.75 with a standard deviation of 4.383 and Ogle (2002) which recorded a mean of 13.344 and a standard deviation of 4.244. However, the score of this study (M = 5.35, SD = 4.82) is comparable to the mean for a study related to field dependence/independence (M = 5.1, SD = 3.53) conducted with a population of similar academic background, adult learners without high school diplomas (Donnarumma, Cox, & Beder, 1980). The mean score for all subjects on the identification subcomponent was 5.06 with a standard deviation of 1.98. The mean score for all subjects on the terminology subcomponent was 4.7 with a standard deviation of 2.03. The mean score for all subjects on the complete MTCT was 9.76 with a standard deviation of 2.65. The meaning of these scores can best be viewed within the context of the specific hypotheses investigated.

H1 Subjects who viewed stereographic materials will score higher on tests of visual recall than subjects who viewed nonstereographic materials.

Table 1 presents scores on the identification subcomponent. On the identification subcomponent, no statistically significant difference between the group receiving stereographic materials (M=5.32) and the group receiving nonstereographic materials (M=4.8) was found $F(1,94)=2.71$, $p>.05$). The results of the identification subcomponent do not lend significant support to the hypothesis that the group receiving stereographic materials will perform better than the group receiving nonstereographic materials.

Table 2 presents scores on the terminology subcomponent. On the terminology subcomponent, no statistically significant difference between the stereographic ($M = 4.58$) and nonstereographic conditions (M= 4.82) was observed ($F(1,94)=.26$, $p>.05$). The results of the terminology subcomponent do not support the hypothesis that the group receiving stereographic materials will perform better than the group receiving nonstereographic materials.

Table 3 presents scores on the complete MTCT test. Analysis of the scores of the complete MTCT show no significant difference between those who viewed stereographic materials (M = 9.90) and those who viewed nonstereographic materials (M = 9.62, $F(1,94)=.88$, $p>.05$). The results of the complete MTCT do not lend significant support to the hypothesis that the group receiving stereographic materials will perform better than the group receiving nonstereographic materials.

H2 Field-independent learners will score higher on tests of visual recall than field-dependent learners regardless of assignment to stereographic or nonstereographic treatment.

Table 1 illustrates the means on the identification test organized by level of field dependence/independence. Although the mean on the identification test for field-independents (M = 5.63) was higher than the means for field-neutrals (M = 4.90) and field-dependents (M=4.70), the results of the analysis of variance indicated no statistically significant difference among these means ($F(2, 94)=2.56$, $p>.05$). The results of the identification test do not lend significant support to the hypothesis that field-independents will outperform field-dependents on tests of visual recall.

Table 2 shows the means on the terminology test organized by level of field dependence/independence. Analysis of the scores of the terminology test reveals that field-independents (M = 5.84), scored significantly higher than field-neutrals (M= 4.45), and field-dependents (M = 3.92, $F(2, 94)=9.49$, $p<.05$). The results of the terminology test support the hypothesis that field-independents will outperform field-dependents on tests of visual recall.

Table 3 displays the means of the complete MTCT organized by level of field dependence/independence. Field-independents scored higher on average on the MTCT than field neutrals ($M = 11.54$ v. $M = 9.34$, $t(61)=3.16$, $p<.05$) and field-dependents ($M = 11.54$ v. $M = 8.61$, $t(67)= 4.81$, $p<.05$). Analysis of variance within scores on the MTCT reveals that field-independents significantly outperformed field-dependents lending support to the second hypothesis ($F(2, 94)=14.63$, $p<.05$).

H3. Field-dependent learners who viewed stereographic materials will score higher on tests of visual recall than field-dependent participants who viewed nonstereographic materials.

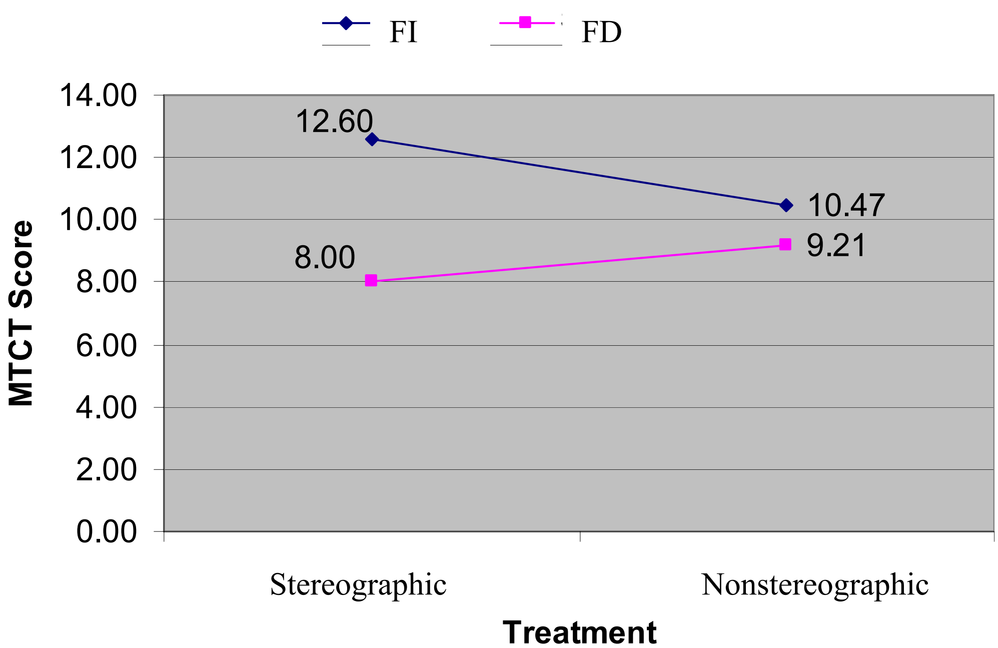
Research suggests that field-dependent learners have difficulty performing visual tasks such as gaining information from an instructional diagram (Witkin et al., 1977; Couch & Moore, 1992). This difficulty is linked to the inability to disembed a figure from its surrounding field. Research in the area of human brain activity suggests that the use of stereographic depth cues may aid in the process of separating a figure from its surrounding field (DeAnglis, 1998). It was therefore hypothesized that stereographic depth cues within an instructional diagram would aid field-dependent learners in obtaining information.

As depicted in Table 1 the scores of the identification subcomponent reveal that field-dependent individuals scored lower in the stereographic group (M = 4.28) than in the nonstereographic group (M = 5.11), though no significant difference can be reported for this test ($t(35)= 1.39$, $p>.05$). The scores of the identification subcomponent do not lend support to the hypothesis that field-dependents given stereographic materials will outperform field-dependents given nonstereographic materials.

On the terminology subcomponent as shown in Table 2, field-dependent individuals in the stereographic group (M=3.72) also scored lower than the field-dependent individuals in the nonstereographic group (M=4.11) with no significant difference found in this subcomponent as well ($t(35) = 0.561$, $p>.05$). No significant support for the third hypothesis is provided by scores on the terminology subcomponent.

As seen in Table 3, field-dependent individuals within the group that received stereographic depth cues (M = 8.00) performed significantly worse on the complete MTCT than field-dependent individuals in the group which received nonstereographic materials (M = 9.21, $t(35)= 2.12$, $p<.05$). This data suggests that field-dependent learners who receive nonstereographic materials scored higher on tests of visual recall than field-dependent learners who receive stereographic materials which is contrary to the relationship predicted by the third hypothesis. Further analysis reveals that field-independent subjects who received stereographic materials (M= 12.60) outperformed field-independent subjects who received nonstereographic materials (M =10.47, $t(30)$=2.09, $p<.05$). Analysis of variance reveals a statistically significant stereographic visuals X field dependence/independence interaction ($F(2, 94)= 4.50$, $p<.05$). This interaction is directly contrary to the hypothesis that field-dependent participants with stereographic visuals will perform better than field-dependent participants with nonstereographic visuals (See Figure 2).

Figure 2 Interaction of field dependence across treatment



Summary of results

There was no significant difference between the group of participants who received stereographic materials and the group who received nonstereographic materials. As expected, field-independent participants scored higher on tests of visual recall than field-dependent participants. The desired effect of introducing stereographic depth cues as a treatment did not serve to improve the performance of field-dependent subjects but conversely served to exacerbate their difficulties gathering information from visuals. The introduction of stereographic depth cues did improve the performance of field-independent participants. This interaction direction between level of field dependence and presence of stereographic visuals was contrary to the predictions made based on the review of literature. Therefore, a reexamination of previous research related to these two factors and their relationship to the results was necessary to discuss possible explanations for this unexpected interaction direction.

Limitations

In describing the evaluation of media as learning tools, Lockee, Moore, and Burton (2001) have suggested that examining the impact of the attributes of a medium provided a more informative approach then examining the impact of the medium as a whole. Therefore, the results of this study may not generalize to the evaluation of all stereographic virtual environments but rather provide information related to the effect of an autostereoscopic virtual environment with the specified hardware configuration used within an instructional context.

Another possible limitation to the generalizability of this study was addressed in relation to the relatively low score on the GEFT. Although the score of this study was considerably low compared to the majority of means within FDI research, this score was consistent in both mean and standard deviation to research conducted with a similar population (Donnarumma, Cox, & Beder, 1980). However, due to the relatively low mean, these results may not generalize beyond the population studied.

Discussion

Field dependent learners do not perform as well on tasks of visual recall as field independent learners (Worley & Moore, 2001; Ogle, 2002; Dwyer & Moore, 1992). This difference in performance is often attributed to the differences which exist between the ways in which field dependent learners and field independent learners structure information (Dwyer & Moore, 2001).

The results of this study were consistent with Worley and Moore (2001) and Dwyer and Moore (1992) which found that field independent subjects performed significantly better on the Modified Total Criterion Test, a test of visual recall, regardless of assignment to treatment group.

One of the aims of this study was to determine if stereographic virtual environments could provide field dependent learners with a cue to generate structure around the information in the same manner that field independent learners generate structure on their own. The results of this study indicated that field dependent individuals performed worse when exposed to stereographic depth cues. Conversely, the performance of field independent individuals was higher in the group receiving stereographic materials than in the group receiving nonstereographic materials. The direction of this significant interaction is contrary to the study's third hypothesis which predicted that field dependent learners who viewed stereographic materials would score higher on tests of visual recall than field dependent participants who viewed nonstereographic materials. This hypothesis was based on the strategy of using stereographic depth cues to highlight only relative information for field dependent learners.

Despite this strategy, the results indicated that stereographic depth cues did not assist the field dependent individuals in providing structure to the instruction. Instead, the addition of stereographic depth cues served to significantly inhibit the performance of field dependent individuals in particular. Witkin (1976) suggested that field dependent individuals pay attention to the most salient cues within the environment whether these cues are relevant or not. Based on this understanding, the author speculated that the stereographic depth cues served to distract field dependent individuals from relevant information in some way. Although, these cues were only used with relevant information within the instruction, their presence may have caused field dependent learners to become confused as to which information was relevant. This level of distraction was a possible explanation of the impact on the performance of field dependent learners.

As the interaction direction demonstrated in Figure 2 demonstrates, field independent learners within the stereographic group performed better than field independent learners within the nonstereographic group. Dwyer and Moore (1992) suggested that field independent learners are able to analyze the components of a visual and interpret their relationship more effectively than field dependent learners. Therefore the author of this study speculated that field independent learners were more likely to incorporate the stereographic depth cues as an additional organizational element within the virtual environment and then utilize these cues to more effectively process information from the instruction. Although stereographic virtual environments did not serve to improve the performance of field dependent individuals as hoped, the results of this study did suggest that the level of FDI of the subject did influence the evaluation of the effectiveness of the SVE as a learning tool.

If current trends continue, the complexity of stereographic virtual environments and other visual media will increase parallel to the evolution of technologies associated with the display and processing of data. The use of stereographic depth cues within instructional media will also increase as designers seek to leverage these technologies to communicate complex three-dimensional concepts. These depth cues are already present in instructional materials within the domains of chemistry, biology, and mathematics (Morgan et al., 2002; Roussos et al., 1999). As the use of these technologies within education proliferates, evaluation of impact on learning becomes essential.

Previous research has examined the impact of using stereographic depth cues to focus the attention of learners on specific components of instruction. Cartonnet (1999) for instance found that subjects receiving a stereographic presentation performed twice as well as the group receiving a nonstereographic presentation on a series of questions related to the presentation. Trindade et al. (2002) also indicated that the presence of stereographic depth cues within the environment improved student performance in recognizing structural elements within the crystallization process. These studies suggest that stereographic depth cues within SVEs can improve performance for learners related to certain visual tasks. However, these studies did not address the influence of learners' level of FDI on performance related to these tasks.

The results of this study suggested that FDI should be taken into account when evaluating the effectiveness of SVEs as learning tools. Without the collection of data related to FDI, this study would have indicated no significant difference in visual recall based upon stereographic depth cues. This is due to the fact that as the FDs performed worse when presented with SVEs, FIs performed better. This phenomenon would not have been apparent in the results of this study without examining FDI as a variable since there was no evidence of a main effect due to presence of stereographic cues in the overall scores of visual recall. Therefore, without the assessment of level of FDI, little insight into the effectiveness of this autostereoscopic virtual environment as a learning tool could have been made.

REFERENCES

Adler, F. H. (1987). *Adler's physiology of the eye: Clinical application* (8th ed.) St. Louis: Mosby.

Allison, D., Wills, B., Bowman, D., Wineman, J., & Hodges, L. (1997). The virtual reality gorilla exhibit. *IEEE Computer Graphics and Applications, 17*(6), 30-38.

Amador-Campos J. A., & Kirchner-Nebot, T. (2001). Children's embedded figures test and matching familiar figures test: factorial structure for boys and girls from 6 to 11 years old. *Perceptual and Motor Skills, 93*(3):709-12.

Arnold, J. Farrell, M., Pettifer, S., & West A. (2002). Performance of a skilled motor task in virtual and real environments. *Ergonomics, 45*(5)*,* 348-362.

Arthur, K., Booth, K., Ware, C. (1993) Evaluating 3D task performance for fish tank virtual worlds. *ACM Transactions on Information Systems (TOIS), 11*(3). 240-265.

Bakker, N., Werkhoven, P., & Passenier, P. (1999). The effects of proprioceptive and visual feedback on geographical orientation in virtual environments. *Presence Teleoperators and Virtual Environments, 8*(1), 36-53.

Biggs, S., & Srinivasan, M. (2002). Haptic interfaces. In K. M. Stanney (Ed.), *Handbook of virtual environments.* (pp. 93-116). London: Erlbaum.

Bowman, D., Hodges, L., Allison, D., & Wineman, J. (1999). The educational value of an information-rich virtual environment. *Presence: Teleoperators and Virtual Environments, 8*(3)*,* 317-331.

Bowman, D. A., Gabbard, J. L., & Hix, D. (2002). A survey of usability evaluation in virtual environments: Classification and comparison of methods. *Presence: Teleoperators and Virtual Environments*, *11*(4)*,* 404-424.

Bowman, D., Kruijff, E., LaViola, J., & Poupyrev, I. (2001). An introduction to 3D user interface design. *Presence: Teleoperators and Virtual Environments*, *10*(1), 96-108.

Cartonnet, Y. (1999). Experimental research on the relations between stereoscopic vision and mechanical designers' activities, with a view to c.a.d. teaching. *International Journal of Technology and Design Education 2*(2), 153-172.

Carney, R. N., & Levin, J. R. (2002). Pictorial illustrations still improve students' learning from text. *Educational Psychology Review, 14*(1), 5-26.

Clark, R. E. (1983). Reconsidering research on learning from media. *Review of Educational Research*, 53(4), 445-459.

Cobb, S., Nichols, S., Ramsey, A., & Wilson, J. (1999). Virtual reality-induced symptoms and effects (VRISE). *Presence: Teleoperators and Virtual Environments, 8*(2)*,* 169-186.

Cobb, S., & Neale, H. (2002). Development and evaluation of virtual environments for education. In K. M. Stanney (Ed.), *Handbook of virtual environments.* (pp. 911-936). London: Erlbaum.

Coren, S. & Girgus, J. S. (1978). *Seeing is deceiving: The psychology of visual illusions.* Hillsdale, N.J.: Erlbaum.

Couch, R.A., & Moore, D. M. (1992). The effects of imagery rehearsal strategy and cognitive style on the different learning of different levels of instruction. *International Journal of Instructional Media*, *19*(1), 53-63.

Cruz-Neira, C., Sandin, D., & DeFanti, T. (1993). Surround screen projection-based virtual reality: The design and implementation of the CAVE. *International conference on computer graphics and interactive techniques.* New York: ACM Press.

Darken, R., Allard, T., & Achille, L. (1998). Spatial orientation and wayfinding in large-scale virtual spaces: An introduction. *Presence: Teleoperators and Virtual Environments 7*(2)*,* 101-107.

Davis, E., & Hodges, L. (1997). Human steropsis, fusion, and stereoscopic virtual environments. In R. Seidel, & P. Chatelier, (Eds.), *Virtual reality, training's future*. (145-173). New York: Plenum Press.

DeAnglis, G., Cumming, B., & Newsome, W. (1998). Cortical area MT and the perception of depth. *Nature, 394*(13)*,* 677-680.

Deanglis, G. (2000). Seeing in three dimensions: The neurophysiology of stereopsis. *Trends in Cognitive Sciences 4*(3), 80-90.

Dick, W., Carey, L., & Carey, J., (2004). *The Systematic Design of Instruction* (6th ed.) Boston: Allyn & Bacon.

Dillon, A., & Watson, C. (1996). User analysis in HCI: The historical lessons from individual differences research. *International Journal of Human-Computer Studies 45*(6), 619-637.

Driver, J., & Baylis, G. C. (1996). Edge-assignment and figure-ground segmentation in short term visual matching. *Cognitive Psychology, 31,* 248-306.

Durlach, N., & Mavor, A. (1995). *Virtual reality: scientific and technological challenges.* Washington, D.C.: National Academy Press.

Dwyer, F. M. (1978). *Strategies for improving visual learning.* State College: Learning Services.

Dwyer F. M., & Moore, D. M. (1992). Effect of color-coding on visually and verbally oriented tests with students of different field-dependence levels. *The Journal of Educational Technology Systems, 20*(4), 311-320.

Dwyer, F. M. & Moore D. M. (2001). The effect of gender, field dependence, and color-coding on student achievement of different educational objectives. *International Journal of Instructional Media 28*(3), 309-318.

Farish, M. (1999). Limit experience: A UK automotive company is getting to grips with the latest in VR technology. *Engineering, 240*(8)*,* 33-35.

Fencott, C., Van Schaik, P., Ling, J., & Shafiullah, L. (2003). The effects of movement of attractors and pictorial content of rewards on users' behavior in virtual environments: An empirical study in the framework of perceptual opportunities. *Interacting with Computers, 15*(1), 121-140.

Freeman, J., Avons, S., Pearson, D., & Ijsselstein, W. (1999). Effects of sensory information and prior experience on direct subjective ratings of presence. *Presence: Teleoperators and Virtual Environments, 8*(1)*,* 1-13.

Fröhlich, B., & RyaPlate, J. (2000). The cubic mouse: A new device for three-dimensional input. *Conference proceedings on human factors and computing systems*, (pp. 526-531). New York: ACM Press.

Gagne, R., Briggs, L., & Wager, W. (1992). *Principles of Instructional Design* (4th ed.). Boston: Wadsworth.

Ghinea, G. & Chen, S. (2003). The impact of cognitive styles on perceptual distributed mutimedia quality. *British Journal of Educational Technology 34*(4), 393-406.

Gobbetti, E., Pili, P., Zorcolo, A., & Tuveri, M. (1998). Interactive virtual angioscopy. *IEEE Visualization Proceedings,* 435-438.

Hagberg, B., Samuelsson, G., Lindberg, B., & Dehlin, O. (1991). Stability and change of personality in old age and its relation to survival. *Journal of Gerontology 46*(6), 285-291.

Harm, D. L. (2002). Motion sickness neurophysiology, physiological correlates, and treatment. In K. M. Stanney (Ed.), *Handbook of virtual environments* (pp.637-661). London: Erlbaum.

Hernandez, A., Basset, O., Bremond, A., & Magnin, I. (1998). Stereoscopic visualization of three-dimensional ultrasonic data applied to breast tumours. *European Journal of Ultrasound. 8*(1), 51-65.

Howard, I. P., & Rogers, B. J. (1995). *Binocular vision and stereopsis.* New York: Oxford University Press.

Johnson, A., & Leigh, J. (2002). Quickworlds: Teacher-driven VR worlds in an elementary school curriculum. *ACM conference abstracts and applications,* Chicago: ACM.

Kalat, J. (1995). *Biological psychology.* Pacific Grove, CA: Brookes/Cole Publishing.

Keefe, D., Acevedo, D., Moscovich, T., Laidlaw, D., & LaViola, J. (2001). CavePainting: A fully immersive 3D artistic medium and interactive experience. *Proceedings of the 2001 Symposium on Interactive 3D Graphics*.

Kiewra, K. A. & Frank. B. M. (1985). "Cognitive style: Effects of structure at acquisition and testing." ERIC Microfiche ED261072

Kettle, S.F. (1999). Modified stereographic projections of point groups and diagrams of their irreducible representations. *Journal of Chemical Education. 76*(5), 675-678.

Kennedy, R., Stanney, K., & Dunlap, W. (2000). Duration and exposure to virtual environments: Sickness curves during and across sessions. *Presence: Teleoperators and Virtual Environments, 9*(5)*,* 463-472.

Lawson, B. D., & Graeber, D.A. (2002). Signs and symptoms of human syndromes associated with synthetic experiences. In K. M. Stanney (Ed.), *Handbook of virtual environments.* (pp.589-618). London: Erlbaum.

Leader, L., & Klein, J. (1996) The effects of search tool type and cognitive style on performance during hypertext database searches. *Educational Technology Research and Development*, *44*(2), 5-15.

Levin, J. R., Anglin, G. J., & Carney, R .N. (1987). On empirically validating functions of pictures in prose. In D. Willows & D. Houghton (Eds.), *The psychology of illustration: Vol 1. Instructional issues*. (pp. 51-80). New York: Springer-Verlag

Lockee, B., Moore, M., & Burton, J., (2001). Old concerns with new distance education research. *Educause Quarterly 24*(2), 60-62.

May, J. G., & Badcock, D. (2002). Vision and virtual environments. In K. M. Stanney (Ed.), *Handbook of virtual environments* (pp.791-806). London: Erlbaum.

McLellen, H. (2004). Virtual realities. In D. Jonassen (Ed.), *Handbook of research on educational communications and technology.* (461-498). Mahwah, NJ: Erlbaum.

Moore, D. M., Burton, J. K. & Myers, R. (1996). Multiple-channel communication: the theoretical and research foundations of multimedia. In D. Jonassen (Ed.) *Handbook of Research for Educational Communications and Technology.* New York, Simon & Schuster MacMillan**:** pp. 851-875.

Morgan, T., Kriz, R., Howard, S., das Neves, F., & Kelso, J. (2002). Extending the use of collaborative virtual environments for instruction to K-12 schools. *INSIGHT, 1,* 67-82.

Nesbitt, K., Gallimore, R., & Orenstein, B., (1999). Investigating the application of virtual environment technology for use in the pertroleum exploration industry. *ACSC, 00,* 181-188.

Ogle, T. (2002). *The effects of virtual environments on recall in participants of differing levels of field dependence.* Published doctoral dissertation, Virginia Tech: Blacksburg, VA.

Pertaub, D., Slater, M., & Barker, C. (2002). An experiment on public speaking anxiety in response to three different types of virtual audience. *Presence: Teleoperators and Virtual Environments 11*(1) 68-78.

Rickards, J., Fajen, B., & Sullivan, J. (1997). Signaling, notetaking, and field independence-dependence in text comprehension and recall. *Journal of Educational Psychology, 89,* 508-517.

Roussos, M., Johnson, A., Mohler, T., Leigh J., Vasilikas, C., & Barnes, C. (1999). Learning and building together in an immersive virtual world. *Presence: Teleoperators and Virtual Environments, 8*(3)*,* 247-263.

Salzman, M., Dede, C., Loftin, R., & Chen, J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators and Virtual Environments, 8*(3)*,* 293-316.

Sharp Laboratories of Europe, Ltd. (2003). *Performance of a convertible 2D and 3D parallax barrier autostereoscopic display.* Oxford: Great Britain. Retrieved July, 15, 2004, from www.sle.sharp.co.uk/pdf/Sharp%20IDRC_00_P45.pdf

Smith, J., Connell, D., & Swift J. (1999). Stereoscopic display of atomic force microscope images using anaglyph techniques. *Journal of Microscopy,196*(3), 347-351.

So, R., Ho, A., & Lo, W. T. (2001). A metric to quantify virtual scene movement for the study of cybersickness: Definition, implementation, and verification. *Presence: Teleoperators and Virtual Environments, 10*(2)*,* 193-215.

Stanney, K. M., & Zyda, M. (2002). Virtual environments in this 21st century. In K. M. Stanney (Ed.), *Handbook of virtual environments* (pp.1-14). London: Erlbaum.

Steinwand, D., Davis, B., & Weeks, N. (2002). *Geowall: Investigations into low-cost stereo display systems.* USGS Open File Report . Retrieved October 17, 2004, from http://geowall.geo.lsa.umich.edu/papers/Geowall.pdf

Sumrow, M. (2002). Norsk Hydro optimizes well paths with virtual reality technology. *The Oil and Gas Journal*, 100, 53-55.

Thompson, M. A. & Thompson. M. E. (1987). Field dependence-independence and learning from instructional text. ERIC Microfiche ED285563

Tinajero, C., & Paramo, M.F. (1997). Field dependence-independence and academic achievement: a rexamination of their relationship. *British Journal of Educational Psychology, 67,* 199-212

Trindade, J., Fiolhais, C., & Leandro, A. (2002). Science learning in virtual environments: A descriptive study. *British Journal of Educational Technology, 33*(4), 471-488.

Thwaites, H. (1993). Three dimensional media technologies: Potentials for study in visual literacy. In N. Metallinos. (Ed.), *Verbo-visual literacy: Understanding and applying new educational communication media technologies.* (201-208). Montreal: 3DMT.

Vince, J. (2004). *Introduction to virtual reality*. London: Springer-Verlag.

Waurzyniak, P. (2000). Virtual models gain favor. *Manufacturing Engineering, 124*(4) 34-47.

Welch, R. B. (2002). Adapting to virtual environments. In K. M. Stanney (Ed.), *Handbook of virtual environments* (pp.619-636). London: Erlbaum.

Weissman, M. A. (1988). Stereoscopic 3D imaging. *ESD: The Electronic System Design Magazine, 18*(4)*,* 59-64.

Witkin, H.A., Dyk, R.B., Faterson, H., Goodenough, D., Karp, S., (1974). Psychological differentiation: Studies of development. Potomac, Lawrence Erlbaum Associates

Witkin, H. A., Goodenough, D. R., & Karp, S. (1967). Stability of cognitive style from childhood to young adulthood. *Journal of Personality and Social Psychology, 7*(2)*,* 291-300.

Witkin, H. A., Oltman, P., Raskin, E., & Karp, S. A. (1971). *Group embedded figures test manual*, Redwood City, CA: Mind Garden, Inc.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977a). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research, 47,* 1-64.

Witkin, H. A., Moore, C.A., Friedman, F., Owen, D., & Raskin, E. (1977b). Role of field-dependent and field independent cognitive styles in academic evolution: a longitudinal study. *Journal of Educational Psychology 69*: 197-211.

Wikin, H.A, & Goodenough, D. R, (1981). *Cognitive styles, essence and origins : field dependence and field independence,* New York : International Universities Press.

Worley, G., & Moore, D. M. (2001). The effects of highlight color on immediate recall on subjects of different cognitive styles. *International Journal of Instructional Media, 28*(2)*,* 169-180.

Yoon, G.S. (1994). the effect of instructional control, cogntive style, and prior knowledge on learning of computer-assisted instruction. *Journal of Educational Technology Systems*, 22, 357-370.

Appendix A: Sample Instructional Materials

Figure 3 Nonstereographic instructional materials

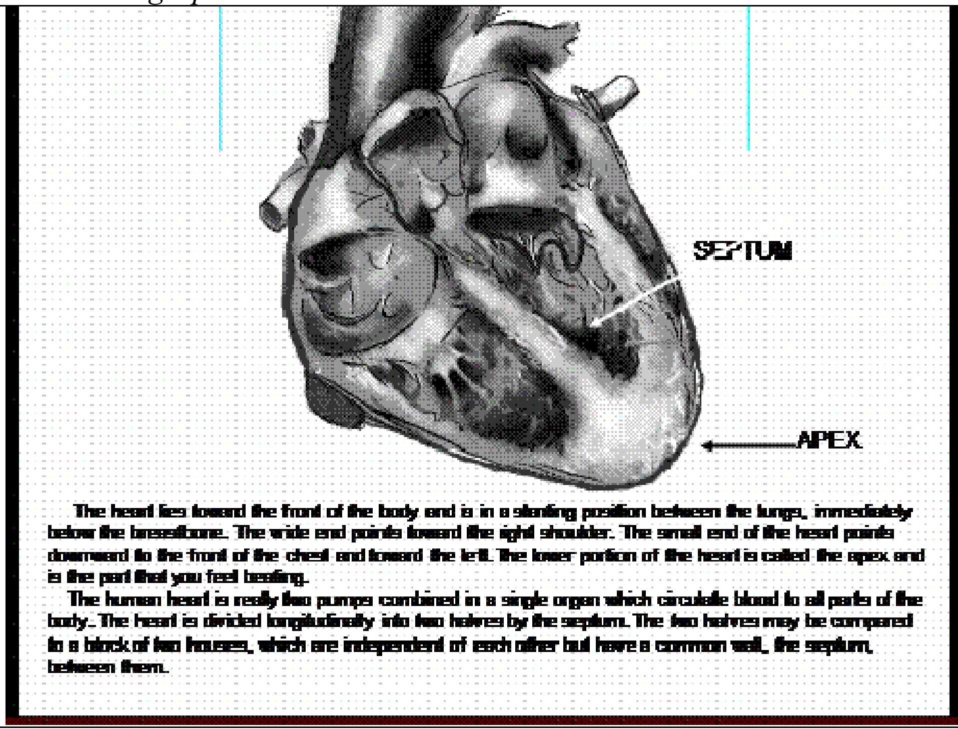
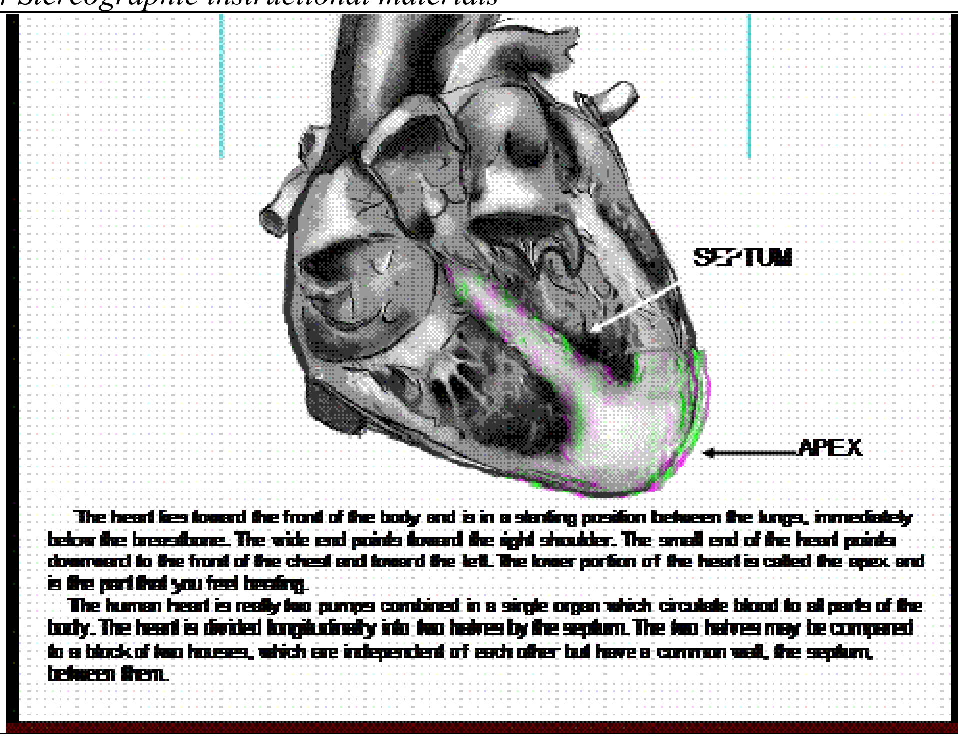


Figure 4 Stereographic instructional materials



Appendix B: Sample Stereographic Equipment Verification (SEV)

Figure 5 Nonstereographic version

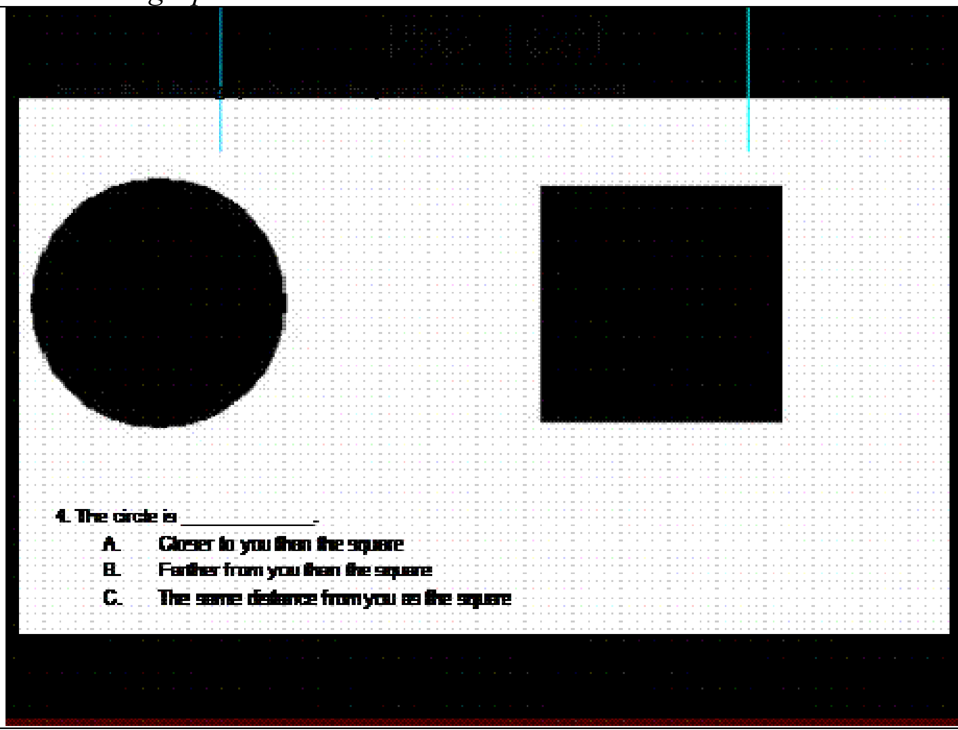
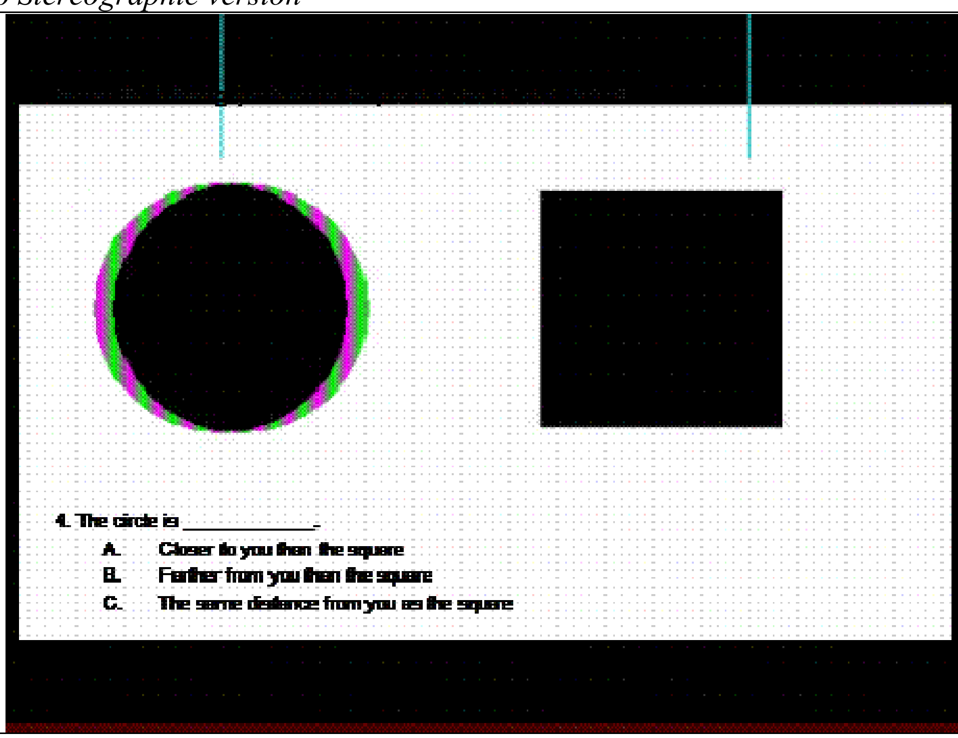
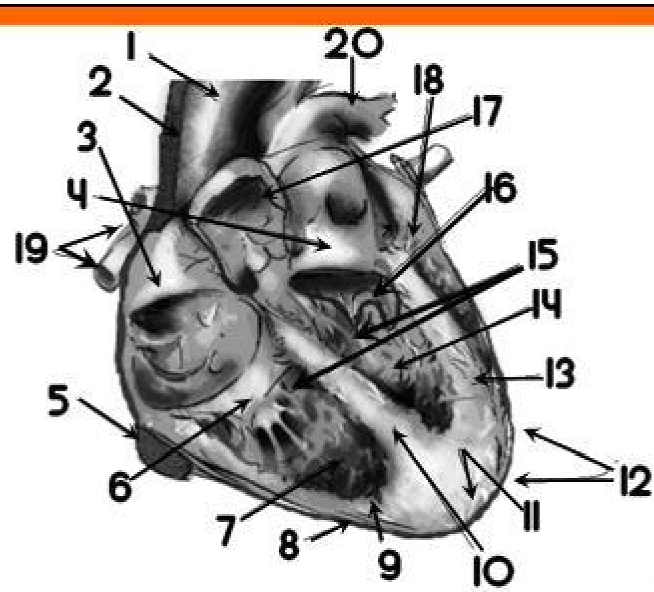


Figure 6 Stereographic version



Appendix C: Sample Identification Test



6.) Arrow number one (1) points to the

A. Septum
B. Aorta
C. Pulmonary Artery
D. Pulmonary Vein
E. None of These

Appendix D: Sample Terminology Test Page

Directions: Select the answer you feel best answers the question and mark the corresponding circle.

26. _____ is(are) the thickest walled chamber(s) of the heart.

A. Auricles
B. Myocardium
C. Ventricles
D. Pericardium
E. Endocardium

27. The contraction of the heart occurs during the ______ phase.

A. Systolic
B. Sympathetic
C. Diastolic
D. Parsympathetic
E. Sympatric

28. Lowest blood pressure in the arteries occurs during the _____ phase.

A. Sympatric
B. Sympathetic
C. Diastolic
D. Systolic
E. Parasympathetic

Appendix E: Individual Scores

Table 4

Scores on GEFT, Identification, Terminology, and MTCT

ID	TREAT	GEFT	Identification	Terminology	MTCT
1	0	7	3	9	12
2	1	18	4	8	12
3	0	5	6	3	9
4	1	10	7	5	12
5	0	6	6	5	11
6	1	14	12	5	17
7	0	1	3	6	9
8	0	0	3	8	11
9	1	3	6	1	7
10	0	1	5	3	8
11	0	0	5	5	10
12	1	1	3	5	8
13	0	4	2	6	8
14	0	6	4	3	7
15	1	0	5	7	12
16	1	12	6	5	11
17	1	2	4	6	10
18	0	16	7	9	16
19	0	9	5	7	12
20	1	7	7	6	13
21	1	4	4	4	8
22	0	8	4	5	9
23	0	4	2	5	7
24	1	2	6	0	6
25	1	2	5	2	7
26	0	0	5	2	7
27	1	0	1	7	8
28	0	5	3	2	5
29	1	2	6	2	8
30	0	7	5	4	9
31	1	10	9	9	18
32	0	1	7	4	11
33	1	15	6	6	12
34	0	3	4	3	7
35	1	0	5	3	8
36	0	1	8	6	14
37	1	0	3	6	9
38	0	9	2	5	7
39	1	5	7	4	11
40	1	9	8	6	14
41	1	9	5	3	8
42	0	0	8	2	10