The Effects of Virtual Environments on Recall in Participants of Differing Levels of Field Dependence

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(Abstract)

Virtual environments are visually dominant systems. It seems that individuals' visual perception abilities would have an effect on their performance in a virtual environment. One such visual perception ability that seems a logical fit for study in virtual environments is that of disembedding ability. Disembedding ability is one part of a greater psychological construct known as field dependence.

This research investigates how the learner characteristic of field dependence affects learning outcomes in virtual environments In order to examine the effect of virtual environments on recall among learners of differing levels of field dependence, the following specific questions and hypotheses were formed:

1) Does the use of virtual environments affect participants' performance in a task of recall?

2) Do participants of different levels of field dependence perform differently on a task of recall when presented with virtual environments versus static images?

3) Do field-dependent participants score higher on a test of recall when presented with a virtual environment?

An experimental design using a sample of Virginia Tech students was employed in this study. The analysis consisted of a 2 X 2 factorial design with main effects for two levels of field dependence (field dependent and field independent), two levels of image representation (virtual environment versus static images), and interaction effects between the two factors.

The factorial analysis showed no significant difference in recall test scores for the two treatments. Likewise, there was no significant difference in test scores for field dependent participants who received the virtual-environment treatment versus the static-image treatment. However, a significant interaction existed between field dependence and

treatment type, favoring the field-independent participants who received the virtual-environment treatment.

It can be concluded from this study that virtual environments have no effect on the recall ability of field-dependent learners. Further research might focus on other individual differences, such as spatial ability, that may have an effect on field-dependent learners’ strategies for working in a virtual environment.

The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood; who strives valiantly; who errs and comes short again and again, who knows the great enthusiasms, the great devotions, and spends himself in a worthy cause; who at best, knows the triumph of high achievement; and who, at the worst, if he fails, at least fails while daring greatly, so that his place shall never be with those cold and timid souls who know neither victory nor defeat.

-Theodore Roosevelt, *Citizen in a Republic*, April 23, 1910

DEDICATION

This work is dedicated to two people. The first is my wife Gwendolyn, who has always encouraged me to pursue happiness. Without her support, I would not be who I am today. May we always laugh and love, and enjoy a rewarding life together. The second is our first child, whose arrival, as of this writing, we anxiously await.

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Most of all, I thank my wife for her willingness to go on this ride with me, no matter the outcome.

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CHAPTER 1: INTRODUCTION

Over the course of the last 15 years, virtual environments have gained increased acceptance as instructional tools for visual learning tasks. Research into the instructional use of virtual environments became more prevalent during the 1990s (Johnson, Moher, Leigh, Vasilakis, Barnes, 1999; Rose 1995; Salzman, Dede, Loftin, & Chen, 1999; Winn 1993, 1999). There are examples of research on collaboration in instructional virtual environments and evaluation of the general "effectiveness" of virtual environments in instructional situations. The Narrative-based Immersive Constructionist/Collaborative Environments (N.I.C.E) project at the University of Illinois is an example of immersive virtual environments being used in research with young children (Johnson, Moher, Leigh, Vasilakis, & Barnes, 1999).

Virtual environments are visually oriented devices, and much of the research done to date has focused on the different aspects of the technology and their effects on learners. There is a need for more study of the interaction of learner characteristics with the characteristics of virtual environments (Salzman, Dede, Loftin, & Chen, 1999). Being visually dominant systems, it would seem that individuals' visual perception abilities would have an effect on their performance in a virtual environment. One such visual perception ability that appears as a logical fit for study in virtual environments is that of disembedding ability. Disembedding ability is one part of a greater psychological construct known as field dependence.

The cognitive style of field dependence is a concept built around one's perceptual style or approach when confronted with a structure embedded in a visual field (Witkin et al., 1971). Field dependent individuals have difficulty separating individual shapes from a complex field (Newbigging, P.L., 1954; Witkin, H.A., 1965). One's ability to disembed a shape from a larger visual field or background is important in many virtual environment tasks such as finding one's way through an environment, selecting objects, etc. This disembedding ability may be an important individual characteristic with an effect on learning in a virtual environment as well. Field dependence has been studied for many years (Dwyer & Moore, 1992; Messick, 1970; Witkin, 1950; Witkin, 1965; Witkin, Goodenough, & Oltman, 1979; Witkin, Oltman, Raskin, & Karp, 1971) but has not been explored as a characteristic of learners that may affect their experience and success in virtual environments.

Need for the Study

Research in the effects of learners' field dependence on learning in virtual environments could assist in understanding the ways people go about learning in a virtual environment. Additionally, it may help to establish the optimal mix between visual realism and clarity required for the acquisition of new skills, knowledge, and attitudes by learners with differing cognitive styles. It may be that some learning tasks in a virtual environment are ideally suited for field dependent learners, while others negatively affect field dependent individuals and should be avoided. There is very little study on how learner characteristics interact with the features of virtual environments to aid or inhibit learning. Salzman, Dede, Loftin, and Chen's (1999) model of learning in virtual environments takes into account individual characteristics and points out this ripe field for virtual environments research.

Computer technology advances at such a rate that what is expensive and difficult today is commonplace within a few years. Still, any reduction in the expense or development time and skills required to use real-time virtual environments to educators is a desirable goal today. If expensive, specialized computers and years of programming experience are required for the development and use of virtual environments in education, the technology will be slow in disseminating to a wider audience.

An understanding of how learner characteristics such as field dependence interact with characteristics of the virtual environment can help improve the design and implementation of virtual environments used for learning. Identifying if knowledge can be acquired in a non-immersive Virtual Reality Modeling Language (VRML) world on a desktop computer can make the use of a virtual environment for instruction, in a high school laboratory for example, more feasible than if a head-mounted display (HMD) and high-end graphics workstation is required.

Because of the relatively recent emergence of virtual environments for instruction outside the military, popular misconceptions abound. Movies and television shows give the impression that virtual environments' effectiveness is directly correlated to the level of immersion and visual realism. Based on a survey sent to instructional designers, computer scientists, and media experts, Dennen and Branch (1995) concluded that virtual environments do not, for example, require full immersion and suggest that the level of immersion required be carefully evaluated during the design of instruction.

Much of the research into virtual environments for instructional use focuses on variables within the environment: the software and hardware that provide the experience. If instructional virtual environments are evaluated with attention to learner characteristics, field dependence may be of interest because of its possible interaction with learning and transfer, as an explanation for the effects of the experience, or as a characteristic to be designed for.

Purpose of the Study

While Salzman, Dede, Loftin, and Chen (1999) account for different learning styles in their model of concept learning in virtual environments, they also cite the need for further exploration of the effect of individual characteristics on the learning outcomes of virtual environments. It is the purpose of this study to isolate field dependence as a learner characteristic and examine its effect on learning in a virtual environment.

Tying learner characteristics and the features of virtual environments together into a cohesive framework for the design of instruction in virtual environments would provide instructional designers with the tools they need to best apply the technology of virtual environments to instructional problems. Instructional virtual environments of all kinds, from the desktop to fully immersive systems, could be improved.

With current graphics-processing power and display devices such as head-mounted displays (HMDs) and the CAVE Automated Virtual Environment (CAVE), it is possible to create high-resolution, highly immersive virtual environments. The question, “How real can we make it?” often comes up in the context of improving the technology, but it is not clear how the virtual environment interacts with different individuals’ cognitive and personality characteristics.

CHAPTER 2: REVIEW OF THE RELEVANT LITERATURE

Virtual Environments

To define virtual environment, a definition of virtual reality is necessary. Virtual reality is the more mainstream term. Popular conceptions range from Window on the World, or desktop applications, to flight simulators involving complex mockups of the physical space combined with motion devices, and to Head Mounted Displays.

At its most basic level, virtual reality is described as a new communication technology that involves the human senses in new ways and allows the user to intuitively interact with data (McLellan, 1996). According to Loeffler and Anderson (1994), there are four main elements that make a system virtual reality: it is three-dimensional, it is computer-generated, it is a simulated environment, and it is rendered in real-time according to the behavior of the user.

If these four criteria for what constitutes a virtual environment are accepted, examples of virtual environments include, but are not limited to, immersive systems. Three-dimensional computer games played on desktop computers and VRML viewed on desktop computers are examples of non-immersive systems that are still real-time, three-dimensional, computer generated, simulated environments. Stereoscopic vision is also possible on a desktop computer, but immersive systems such as the CAVE add a more enveloping visual display and different interaction techniques. By this definition of virtual environment, computer-mediated spaces such as text-based chat rooms are not virtual environments because they do not meet the criteria. However, it could be argued that in a different context, a chat room could fit the dictionary definition of *virtual*, as a substitution for a real space.

What are Virtual Environments?

Why the term *virtual environments* rather than *virtual reality*? Cruz-Neira, Sandin, and DeFanti (1993) state that virtual environment is a more encompassing definition of virtual reality, including the ability to touch, hear, and smell. Virtual reality implies a total substitution of something synthetic for something real, whereas virtual environment is more suitable as a facsimile for a real or imagined environment.

Researchers use the terms interchangeably, and no consensus on preferred usage can be found in the literature. In either case, both terms describe a computer-based, three-dimensional visual experience where the user sees the environment from a first-person perspective. For our purposes, the term virtual environment is used to describe the application itself, whereas virtual reality will refer to the entire genre of devices. Specifically, this study refers to virtual environments that make use of Loeffler and Anderson's (1994) four main criteria: a real-time, computer-generated, three-dimensional, simulated environment.

Thurman and Mattoon (1994) developed a model for categorizing the different types of virtual reality. They list three dimensions upon which virtual reality systems differ: a verity dimension, an integration dimension, and an interface dimension. The verity dimension describes how closely the environment matches physical aspects of reality, on a scale from the physical to the abstract. The integration dimension concerns the extent to which humans are integrated with the computer system, on a low-to-high scale from batch processing, to shared control, to total inclusion. The interface dimension scales from artificial to natural. This dimension refers to input and output devices. The keyboard and mouse combination make up the artificial end of the scale, with body-mounted devices such as data gloves on the natural end.

A Brief History of Virtual Environments

The term *virtual reality* was coined by Jaron Lanier in 1989 (Vince, 1999a) but the concept and technology have existed in various forms since the 1950s. According to Vince, in 1956, Morton Heilig invented "Sensorama" in which audiences passively rode around Manhattan. You saw Manhattan move by you via film, while a pair of handlebars and a seat vibrated, wind blew at speeds according to how fast you traveled, and the smell of car exhaust and food wafted by at specific points along the way. Though not computer-generated, the experience seems to have been quite immersive indeed.

Vince (1999a) goes on to describe flight simulators as the next step in the evolution of virtual reality. Flight simulators began life as mechanical-based flight trainers in 1940 with the development of the Link Aviation trainer. In 1960, Boeing coined the term *computer graphics*, though Ivan Sutherland is thought of as the godfather of computer graphics for his innovative ideas in the field.

In 1963, Sutherland began work on the early forms of what is currently thought of as virtual reality. His work in computer graphics and later with head-mounted displays combined the two technologies that dominate the field to this day.

Tom Furness began developing display systems for pilots in 1966, and in 1971 the first commercially available flight simulator with computer graphic displays was introduced by Redifon Ltd. Computer graphics Research continued in the 1970s with the work of scientists such as Henri Gourad and Bui-Tuong Phong.

Improvements in haptic devices—devices that give touch, or force, feedback—and the introduction of commercial virtual reality was the next shift in the technology (Vince, 1999a). Gloves designed for data entry began to emerge in the early to mid-1980s, and in 1990, J.R. Hennequin and R. Stone developed a tactile feedback glove. VPL Research and Autodesk, Inc. introduced commercially available HMDs in 1989. Further developments in head-mounted display and tactile-feedback technology continued into the 1990s, and in 1992, the CAVE was developed at the University of Illinois. Technologies for the display of information in virtual environments and those that allow interaction with the environment are described in more detail in the next section.

Display Types in Virtual Environments

The technologies that make up the virtual-environments toolkit span from desktop and video applications to HMDs and the CAVE. These technologies may be thought of as being on a continuum of immersion from non-immersed to fully immersed, with Window-on-the-World, or desktop, virtual environments positioned on the non-immersive end of the continuum, and a HMD with auditory and haptic feedback on the immersive end. Figure 3 is not intended as an all inclusive list of the combinations of perception and interaction available in virtual environments; it is an illustration of how sensory stimulation as provided by virtual environments increases with increasingly immersive technologies.

Non-immersed → Fully immersed

Visual Display	Desktop monitor with(out) stereo projection or television	Single-screen stereo projection	HMD, retinal display, BOOM	Multiple-screen stereo projection (CAVE)
Audio	Desktop speakers, surround sound speakers	Desktop speakers, surround sound speakers	Three-dimensional positional headphones	Surround sound speakers
Interaction	Mouse and keyboard	Mouse and keyboard	Wand, data glove, joystick	Wand, data glove, joystick
Feedback	Visual, auditory, haptic feedback	Visual, auditory, haptic feedback	Visual, auditory, haptic feedback	Visual, auditory, haptic feedback
Perspective	Outside-in	Outside-in	Inside-out	Inside-out

Figure 1. Illustration of how the array of sensory stimulation increases with immersion.

As mentioned previously, it is important to note that graphical display is not the only factor in immersion. A brief overview of visual display technologies used in immersive and non-immersive virtual environments follows.

Common visual displays for virtual environments include computer monitors and tabletops used with or without stereo glasses, HMDs, stereo projection on a single screen or multiple screens, and retinal displays.

Computer monitor displays can include any workstation capable of drawing three-dimensional graphics to the screen (Vince, 1999b). Similar to this category are the tabletop displays such as the immersive workbench and the Immersa-Desk (I-Desk), which are rear-projected, single-screen displays similar to large rear-projected televisions. Images can be displayed in stereo, but without the image surrounding the user, the feeling of immersion may be reduced.

HMD technology includes visor-like displays worn by the user as a helmet and Fakespace Inc.'s Binocular Omni-Orientation Monitor (BOOM). HMDs offer 360-degree vision of the virtual environment, thereby blocking out the physical world and providing an immersive experience. Some have built-in stereo headphones for three-dimensional positional sound. Even the best HMDs suffer from a limited field of view and lack of peripheral vision. BOOM displays are similar to HMDs but are attached to counterbalanced articulation arms, which take some of the strain off the user but often require two hands to operate, not leaving any hands free for other tasks (Bowman, 2000; Vince, 1999b).

The retinal display is a new technology in development that draws the image directly on the user's retina. There is potential in this technology as a lightweight, wearable solution for virtual environments, as well as augmented reality. Augmented reality is the drawing of computer-generated visuals over the user's view of the real world, as in the heads-up display in a fighter aircraft (Bowman, 2000).

Multiple-screen stereo projection setups such as the CAVE allow for more than one user to be in the environment, where users are able to see each other in addition to the virtual environment. A wider field of view is cited as one bonus of such systems, though the user is not physically isolated from the real environment as in an HMD. The headgear used in a multiple-screen stereo projection system consists of stereo glasses, which are lightweight and therefore less obtrusive and tiring than an HMD.

The preceding overview of visual display technologies commonly used in virtual environments included some mention of interaction techniques. In order to understand how interaction in virtual environments might affect immersion or presence, an overview to provide familiarity with the common interaction techniques follows.

Interaction Techniques in Virtual Environments

Natural modes of interaction and control have been cited as factors in the feeling of immersion within a virtual environment (Witmer & Singer, 1998). There are several ways in which users can interact with and manipulate a virtual environment, all of which fall under the heading of interaction techniques.

In human computer interaction parlance, an interaction technique is a method for accomplishing some task. Common tasks that make use of interaction techniques in virtual environments include navigation, selection, manipulation, and system control (Vince, 1999c). The following is a brief look at each of these tasks and some of the interaction techniques employed to accomplish them.

Navigation

Navigation is probably the most fundamental of the tasks in a virtual environment. A key aspect of virtual environments is the freedom provided to the user for navigation as he or she desires. The two main tasks in navigating virtual environments are travel and wayfinding. An overview of some interaction techniques for travel and wayfinding follow.

The ability to travel is common to most virtual environments. Being able to move from one location or viewpoint to another is essential in many tasks in virtual environments. Tasks making use of travel include exploration of the environment, searching the environment, and maneuvering within the environment (Bowman, 2000). Exploring the environment can be used for building a mental model of the environment, understanding spatial relationships within the environment, or for no specific task at all. Searching the environment can be used to build spatial knowledge of the environment or for moving to a specific location to complete a task. Maneuvering is often used for shorter, precision movements that provide a new perspective or viewpoint on an object.

There are several metaphors for travel in virtual environments, including the steering metaphor, target-based metaphor, route-planning metaphor, manipulation metaphor, and natural metaphors (Bowman, 2000). The steering metaphor is a continuous specification of the direction of motion, often through pointing, gaze, or some device such as a steering wheel or joystick. The target-based metaphor involves the discrete specification of a goal through pointing, choosing from a list, etc. The route-planning metaphor uses the one-time specification of a path to be traveled by placing markers or moving icons on a map of the environment. The manipulation metaphor is a manual manipulation of the user's viewpoint, by actually moving the viewpoint camera by hand or moving about some fixed object. Natural metaphors include using some physical device such as a treadmill or bicycle or simulating flying or driving. Natural metaphors for travel have proven themselves to be better for some conditions and tasks, but a single best navigation technique for all virtual environments has not been found.

Wayfinding involves exploring an environment, building a cognitive and spatial map of that environment. Wayfinding tasks include explorative searching, naïve searching, primed searching, and specified trajectory movement (Bowman, 2000). Explorative searching is searching without a specific target, while naïve searching is searching for a specific target, with the position of that target being unknown. A primed search is one in which the target position has been seen before. Specified trajectory movement is simply movement along a predefined path.

Three types of knowledge are used to build a cognitive map of an environment: landmark knowledge, procedural knowledge, and survey knowledge. Landmark knowledge involves the properties of an object that can be seen, such as color, size, shape, etc. Procedural knowledge comprises the procedures required to get from one point to another along a path. Survey knowledge is similar to spatial knowledge in that it concerns the location and relationships among objects and the orientation of objects in an environment.

Wayfinding is usually performed from one of two perspectives or reference frames: egocentric or exocentric. The egocentric reference frame involves perception of objects relative to the user's eyes, head, and body. The exocentric reference frame is the perception of objects relative to the position and orientation of an object outside the user's body.

Selection and Manipulation

Selection and manipulation of objects in virtual environments are closely related. Manipulation is the modification of some properties of an object, and objects must be selected prior to being manipulated. Common techniques for selecting objects in virtual environments include touching, ray or cone casting, occlusion (blocking) or framing, naming, and indirect selection. Common goals of selection are indicating a specific object, activating an object, traveling to an object's location, and preparing to manipulate an object (Bowman, 2000). Once selected, common goals of manipulation include moving and placing objects for design, layout, or grouping; using objects as tools; and using objects for travel. Common metaphors for manipulation include a virtual hand, ray casting, hand position mapping, indirect depth mapping, the scaled-world grab, and the world-in-miniature.

System Control

System control is an interaction technique that makes use of other interaction techniques, such as selection and manipulation (Bowman, 2000). System control interactions usually involve tasks such as issuing commands to the system and selecting a tool. System control is often accomplished through floating menus, voice recognition, gesturing and posturing, and implicit controls.

The description of interaction techniques provided here has only scratched the surface of this major area of study in human computer interaction. Interaction techniques should be considered in any discussion of variables in the perception of immersion or presence.

Immersion in Virtual Environments

The term *immersion* is often used as a factor in the sense of presence (McLellan, 1996; Winn, Windschiti, & Thomson-Bulldis, 1999). A strong sense of presence in a virtual environment has been considered a factor in the overall enjoyment of the experience. Immersion differs from presence in that immersion is the physical blocking of the senses from outside stimuli. Immersion increases with an increase of the amount sensory information provided by the system. Immersion is assumed to be a factor in the sense of presence, and the product of a sense of immersion or presence in a virtual environment is an increased perception of the realism of the experience (Winn, Windschiti, & Thomson-Bulldis, 1999).

Presence in Virtual Environments

Presence in virtual environments is the subjective sense of being in one place, while being physically located in another (Witmer & Singer 1998). A sense of presence, a key factor of which is immersion (Taylor, 1997), is commonly used as a descriptor of the virtual reality experience. An exploration of the types of presence studied in distance learning, communication studies, and virtual environments follows.

Tammelin (1998) lists three types of presence: spatial, self-reflective, and social. Spatial presence is the feeling of presence within a space, which is often used to describe the sense of presence in a virtual environment. Self-reflexive presence is the feeling that the environment provides the same responses, or affordances, as their real-world partners. Social presence is the sense of presence in a social encounter, such as speaking to someone on the telephone.

Lombard and Ditton (1997) present six conceptualizations of presence derived from several areas of study, including communication, entertainment, virtual reality, and education. They claim that a sense of presence is important in the use of technologies such as video conferencing, television, computer games, etc., thus more study on what enhances the sense of presence and the effects of the sense of presence in these media is justified. The six conceptualizations of presence offered by Lombard and Ditton are presence as social richness, presence as realism, presence as transportation, presence as immersion, presence as social actor within a medium, and presence as medium as social actor. All of these share a commonality: the fact that the interaction or communication is mediated by the medium disappears for the user, viewer, listener, reader, or learner.

Presence as social richness refers to the perception that a medium is sociable, personal, intimate, etc. Studies in several fields emphasize the need for understanding the role of social presence in computer-based communication and education. McIsaac and Gunawardena (1996) define social presence as the feeling of being present socially in a mediated setting. They state that computer-mediated communication creates a level playing field for participants because characteristics such as gender, race, and physical attributes are not made known.

Lombard and Ditton (1997) define presence as realism—the ability of the medium to provide representations of objects, events, and people that seem like the real artifact. Research in presence as realism often includes work with television and virtual reality applications. Within presence as realism, Lombard and Ditton list two types of realism: social and perceptual. Social realism is the degree to which a medium represents events in a manner that could happen in the real world, while perceptual realism is concerned with the look and sound of things and people. Something can be presented in a realistic setting, thus having high social realism, but if the objects or people do not look realistic, the perceptual realism will be low.

Lombard and Ditton (1997) list three types of presence as transportation. "You are there," is the familiar idea of being transported to a different time and place by a good book, story, movie, etc. and is often cited in terms of virtual reality applications. "It is here" is the feeling that other people, objects, or places are brought to the user. "We are together" transportation is the idea of bringing two or more people together in a shared space such as videoconferencing.

Presence as immersion is the concept of the perceptual and psychological immersion. Many researchers in virtual reality cite immersion as a compelling feature of virtual environments (Salzman, Dede, Loftin, & Chen, 1999; Winn, 1999). Perceptual immersion refers to the degree to which a person's senses are stimulated by the medium—be it virtual reality, a simulator, or movie theater—and how much of the physical environment is blocked by the medium. Psychological immersion refers to being fully engaged in an activity, such as reading a book, watching a movie, playing a video game, or interacting with a virtual environment.

Presence as social actor within a medium involves interaction between people and media, such as television where a personality directly addresses the viewer. An example is talking back to an actor in a movie or television show. Thus, the fact that the interaction is mediated by the technology is lost, and the media personality is thought of as a social actor (Lombard & Ditton, 1997).

Presence as medium as social actor refers to interactions between humans and machines, where people respond to cues provided by the medium. An example is personifying a computer or treating it as though gender or politeness are relevant factors, illogical as it may be. Though most people confirm the counter-logic of such behavior, it is an example of a computer-mediated aspect of a communication experience being ignored (Lombard & Ditton, 1997).

Lombard and Ditton (1997) provide three effects of presence: arousal, vection and simulation sickness, and other physiological effects. Movies, books, video games, etc. attempt to raise arousal levels for entertainment purposes, and one effect of a virtual environment that provides a strong sense of presence could be increased arousal levels. Vection is the feeling that one is moving, as in an IMAX movie of a roller coaster ride or in some immersive virtual environments. One drawback of vection is simulation sickness, where the visual stimuli and vestibular stimuli are not synchronized, causing dizziness and nausea in some users of virtual environments. Other physiological effects include ducking or flinching in response to perceived objects in the environment. Some psychological effects of presence include enjoyment, involvement, task performance, skills training, desensitization, persuasion, memory and social judgement, and parasocial interaction and relationships. Research into these effects is still in its infancy. Of these, task performance and skills training are of special interest in this review of the literature.

The literature on virtual environments commonly defines presence as the suspension of disbelief, or the feeling of "being there." Witmer and Singer (1998) define presence as the feeling of being in a place other than the actual physical location one is in, and specific to virtual environments, experiencing what the computer is generating instead of the real surroundings. Some additional factors influencing the sense of presence include auditory cues, interaction techniques, and artificial representation of oneself. Heeter (1992) identifies three dimensions of presence: personal presence, social presence, and environmental presence. Heeter defines personal presence as the degree to which the virtual environment affects human perception channels, such as sight, sound, and touch. Social presence is described as the perception of being in the virtual environment based on interactions with other people or computer-generated entities. Heeter defines environmental presence as the virtual environment's capacity for modification and response to user input.

In their presence questionnaire, Witmer and Singer (1998) define immersion as the "perception of being enveloped" in a virtual environment. They identify several factors that affect the feeling of immersion, including “isolation from the physical environment, perception of self-inclusion in the virtual environment, natural modes of interaction and control, and perception of self-movement.” Witmer and Singer go on to state that the greater the sense of immersion, the greater the sense of presence will be. They also contend that the sense of immersion is different for everyone (1998).

There is some debate over the meaning of the terms *immersion* and *presence*. Immersion has been identified as a key factor in the sense of presence. Slater (1999) refers to Witmer and Singer’s conception of presence as “immersive response,” while using the term *system immersion* in regard to the qualities that the system imparts, such as surrounding environment, multiple sense support, and shutting out the physical world.

The Case for Virtual Environments in Education and Training

In the 1990s there was an increasing amount of research and a number of applications of virtual environments in higher education and K–12 settings. An examination of the research on learning in virtual environments that provides a basis for the use of virtual environments in education and training follows. Several theories and models of learning that repeatedly emerge from the literature as a best fit with virtual environments are explored as well.

Traub (1994) cites realistic experience as a good case for virtual environments, claiming that it challenges learners to seek knowledge as they do in everyday life. Meredith Bricken (1992) cites virtual environments’ experiential quality as key in learning and feels that shared or multi-user virtual environments afford a social learning experience. Osberg (1993) also praises virtual environments’ ability to allow the learner to experience the information by allowing different perspectives and symbolic representations. Visualization can motivate and stimulate learner interest (Dwyer, 1994).

Winn, Windschiti, and Thomson-Bulldis (1999) claim that virtual environments can allow students to extend their data-gathering abilities, give students all the accurate scientific data they need and encourage good scientific practice. The Virtual Puget Sound project, they will examine whether having students visit an immersive virtual environment is more effective than using a desktop simulation for understanding three-dimensional phenomena. An example of a three-dimensional phenomenon is particle movement, while a phenomenon with fewer dimensions might be the movement of a flood crest down a river. Winn et al. expect that immersive virtual environments will be more effective only when thinking in three dimensions is necessary and when providing tactile feedback adds something to the experience as it does in NewtonWorld, which is part of Project ScienceSpace (Salzman, Dede, Loftin, & Chen, 1999). See page 40 for a more detailed look at Project ScienceSpace.

The idea of using virtual environments as a tool for learning has gained acceptance among educators. In a survey of environmental educators, Taylor and Disinger (1997) found that the sample population accepted virtual environments as a possible tool for environmental education. The educators also felt the features of virtual environments that allow students to have experiences they might otherwise not be able to in the physical world would be the most beneficial.

Winn and Jackson (1999) propose 14 reasons for using virtual environments for education. The propositions are based on 10 years of research focusing mainly on immersive virtual environments. The following is an overview of Winn and Jackson's 14 propositions for the educational use of virtual environments.

1. "Virtual environments are cheaper than high-end physical simulators." (p. 5) Most virtual environments are too complex and expensive to be found in the average school or training facility, but they are less expensive than flight simulators for instance. With a decrease in cost comes a decrease in fidelity, but Caird (1996) found that high fidelity is often not needed for training. According to Caird, even the best virtual environment does not perfectly mimic the real world, and a discrepancy can negatively affect transfer.

2. "Virtual environments are safer than real-world training." (p. 5) Rehearsal for military missions (U.S. Congress, Office of Technology Assessment, 1994) and firefighter training (Bliss, Tidwell, & Guest, 1997) are examples of tasks that are more safely practiced, especially for novices, in virtual environments.

3. "Virtual environments allow quasi-natural interactions with objects." (p. 6) Navigating through an immersive virtual environment and interaction with objects is more natural than using a mouse and keyboard for the same task, but because locomotion is still provided by means of a wand or pointing, it is defined as only "quasi-natural."

4. “Students can learn in virtual environments.” (p. 6) Winn and Jackson cite the Project ScienceSpace (Salzman et al., 1999) work as showing that visualization and manipulation of objects are major factors in learning. Osberg’s (1997) study had children build virtual environments and found significant gains in knowledge and improvement of mental models.

5. “Virtual environments are most useful when they embody concepts and principles that are not normally accessible to the senses.” (p. 7) Winn and Jackson feel that virtual environments allow students to see, hear, and interact with information, concepts, and data outside the range of normal human perception. They state that utilizing this feature to build worlds with such information is much more useful than simply representing something that is available to students in the real world.

6. “Metaphors and analogies are important keys to representing and understanding concepts and principles that are not normally accessible.” (p. 8) It is important that the metaphors used for phenomena usually outside our perception make sense and are appropriate. The next proposition regards the consequences of poorly chosen metaphors.

7. “Mis-chosen metaphors can induce misconceptions.” (p. 8) In a virtual environment about global warming, the designers’ use of trees to represent green plants caused students to mistakenly think that planting more trees would reduce global warming, when the trees were meant to symbolize all green plants as a group.

8. “Virtual environments are most effective when changes in three-dimensional viewpoint contribute to learning.” (p. 8) This proposition agrees with the conclusion in the Project ScienceSpace (Salzman, Dede, Loftin, & Chen, 1999). Winn and Jackson cite a study by Arthur, Hancock, and Telke (1996) where participants in an immersive virtual environment were asked to determine if three-dimensional geometric shapes were the same as shown previously. The participants who were able to freely move around the objects performed better than those participants who were in a fixed position and had to mentally rotate the objects. Thus, being able to freely move around appears to be helpful in the formation of mental models in virtual environments.

9. “Virtual environments allow direct construction of knowledge, bypassing symbol systems.” (p. 9) Winn and Jackson feel that interacting directly with information in a virtual environment allows learners to construct knowledge directly without first

having to learn a symbol system, such as in chemistry. They do admit, however, that learners might form weak or inaccurate mental models in this way.

10. “Virtual environments can be populated with artifacts that act as ‘tools for thought’.” (p. 9) Winn and Jackson offer the Virtual Puget Sound project as an example of students using a virtual environment as a “tool for thought” to solve problems and build theories. They speak of the effect with technology and the effect of technology. Salomon, Perkins, and Globerson (1991) describe the effect with technology as the ability of the learner to perform tasks while using the technology, and the effect of technology as the ability to perform the skill later without the use of the technology. In the Virtual Puget Sound project, students will observe phenomena that occur in Puget Sound, while manipulating variables and observing the effects. It is hoped that the understanding built while in the virtual environment will carry over to good theories of water movement in oceans after the students no longer use the virtual environment.

11. “Virtual environments engender presence by techniques that shift attention from the real world to the virtual world.” (p. 10) Winn and Jackson state that presence increases as the amount of attention given to the virtual environment versus the real world increases. An example is an immersive virtual environment for phobia treatment (Hodges et al., 1995). Winn and Jackson list the effects of presence as increasing enjoyment and engagement, situating learning in meaningful contexts, and improving collaboration.

12. “Presence is related to engagement, enjoyment, and learning, and to the reduction of malaise in virtual environments.” (p. 11) Winn and Jackson admit that presence interacts with other factors in a complex way and that as of yet none of the interactions have been shown to be causal. Presence as a subjective sense may indeed provide a more enjoyable experience for some users, but it has not been shown that presence improves performance in a virtual environment in any specific learning task.

13. “Virtual environments can situate learning experiences in a meaningful context.” (p. 11) Winn and Jackson describe the Global Change virtual environment as putting students in places throughout Seattle that they are familiar with, therefore bringing the subject matter closer to home. The N.I.C.E. project makes learning more

meaningful and motivating to the students because they take part in activities that can be performed in the real world (Johnson, Moher, Leigh, Vasilakis, & Barnes, 1999).

14. "Collaboration is possible, and beneficial, in virtual environments." (p. 11) Winn (1999) had children at two sites work together in the Global Change virtual environment and found that children enjoyed the addition of a companion. Children at a school linked up in the virtual environment with children who were hospitalized for leukemia treatment and worked together to combat global warming. Winn and Jackson (1999) report that having another person to interact with in the virtual environment enhances the experience for children.

Some of Winn and Jackson's propositions have more empirical basis than others, but each is worthy of further research, and the provision of 14 points to investigate is useful for developing a research agenda focused on educational applications of virtual environments. Their propositions are ideas and suggestions that are not intended to be hypotheses, but Salzman, Dede, Loftin, and Chen (1999) have formed some hypotheses regarding learning in virtual environments based on their work with Project ScienceSpace.

A model for how learning occurs in virtual environments is under development by Salzman, Dede, Loftin, and Chen (1999). Their model tries to describe how the features of virtual environments affect, individually and collectively, complex conceptual learning in virtual environments. The model shows the following:

- features of virtual environments are likely to influence the learning process and learning outcomes,
- the ability for virtual environments to influence learning may depend on the concept being learned,
- individual learner characteristics may interact with features of virtual environments to influence learning, and
- it is likely that the affordances provided by virtual environments affect the interaction and learning experiences and thus learning.

The Salzman, Dede, Loftin, and Chen (1999) model describes how virtual reality's affordances interact with several other factors affecting the learning process and determining learning outcomes. The model suggests that features of the virtual environment such as the user's Frame of Reference (FOR), or perspective, and immersion affect the kind of information that the learner attends to (the learning process) and the learner's level of understanding following the instruction (learning outcomes). The concept to be learned plays a role in determining the effectiveness of virtual environments.

Salzman, Dede, Loftin, and Chen (1999) go on to explain how the individual characteristics of the learner, such as age, gender, spatial ability, and experience with computers, may also affect the virtual environment's influence on learning. The interaction between the virtual environment's features and the learner's characteristics has an effect on the interaction experience, or how the user interacts with the environment, and the learning experience, for example the learner's motivation, perceived meaningfulness of the instruction, etc. Both of these variables influence the learning process and outcomes.

The model, as described here, was developed over the course of evaluating NewtonWorld and MaxwellWorld, which are parts of Project ScienceSpace. Evaluations of the two projects led to fine-tuning to each world, and the insight gained in each successive evaluation was used to further elaborate the model. The model for understanding virtual reality's effects on learning is a significant outcome of the work in Project ScienceSpace.

By examining the interactions between virtual environment characteristics, concepts to be learned, individual learner characteristics, interaction experience and learning experience, Salzman et al. have provided a framework for systematic and empirical analysis of virtual reality's effects on learning. By isolating a single variable in the interaction, they were able to determine the effect of motivation in learning outcomes. Though the participants found the immersive environments motivating, motivation was not found to be a significant predictor of performance.

The research performed in Project ScienceSpace can be used as a guide for performing further research on learning in virtual environments due to the careful selection and observation of variables. Work on further exploring any one of the interactions between virtual reality's features and other parts of the model, such as learner characteristics or the concept to be learned, would be of great value to researchers and designers of instructional applications of virtual reality.

A Theoretical Framework for Learning in Virtual Environments

There are many rationales offered by researchers for using virtual environments in education, but several theories of learning as well as instructional strategies appear repeatedly. The most commonly cited as a good fit for learning in virtual environments include: constructivism, experiential learning, social learning, mental model theory, situated learning and meaningful context, and multiple intelligences.

Surprisingly, researchers do not often cite concrete learning as a rationale for incorporating virtual environments into instructional settings. Given the experiential nature of virtual environments, theories like Edgar Dale's Cone of Experience seem like a natural fit with virtual environments. The Cone of Experience is a system for classifying media experiences as they relate to concrete and abstract experiences. Dale believed that linking abstract learning with concrete experience could make learning more meaningful (Seels, 1997). Osberg (1993) offers a possible explanation for the lack of interest in concrete representations,

> However, if we use VR strictly to mimic the real world by using concrete, realistic concept examples, this could limit the learner in terms of that individuals' ability to abstract concepts from the virtual environment to other situations where the concepts are applicable. There is the possibility that the technology may carry too much authority, and be taken too seriously, limiting the way the learner may look at a particular problem (p. 7).

The following are the theories and models of learning and instructional strategies that are repeatedly identified throughout the literature as fitting well with virtual environments.

Constructivism

Constructivist learning theory was introduced by Jean Piaget and has the general view that learning is an active process of constructing rather than acquiring knowledge. Instruction is a process that supports construction of knowledge rather than communication of knowledge (Duffy & Cunningham, 1996). Constructivism agrees with objectivism that there is meaning in the world around us, but states that we construct it through our experiences and perceptions (Duffy & Jonassen, 1991). Therefore, meaning is different for different people, and learning is a process of interacting with others and the physical world. Constructivism is commonly cited as a fit for virtual environments (Dede, 1995; Winn, 1993).

Winn (1993) claims that virtual environments fit best with the theory of constructivism because immersion allows first-person, non-symbolic experiences with information. He feels that immersion allows us to see and touch things that we are not capable of in the real world and to do so in a natural way. Bricken (1990b) states that learning is primarily action and like Winn feels that constructivism is a good match for virtual environments (Bricken, 1990a).

Bricken (1992) feels that the experiential and intuitive nature of virtual environments and their ability to be configured for individual learner characteristics make them particularly well suited to constructivist design. The ability of virtual environments to place the learner and the learning activity directly in a context is a promising aspect that is also supported by constructivist theory.

Experiential Learning

Regian, Shebilske, and Monk (1992) cite virtual reality's ability to experientially engage the student in the learning context. Virtual reality may be able to capitalize on the visual capabilities of the human brain. The research performed by Regian, Shebilske, and Monk (1992) on transfer-of-training research in virtual environments showed that learning spatial-procedural and spatial-navigational skills is possible in a virtual environment. Participants were given a procedural task in a small-scale virtual environment or a navigational task that required configurational knowledge. The procedural group was given either a meaningful task description or no explanation. The participants were able to learn the console procedure in both groups, but providing instructional meaningfulness had no effect. The navigation group was guided through the maze, allowed to freely explore the space, and then given one of three maze navigation tasks. The participants were able to learn the navigation tasks based on the measure used.

Mental Model Theory

Mental model theory is a theory of cognition concerned with the visual representations of concepts in our “mind’s eye.” Mental model theory is not limited to spatial knowledge but includes perception of the causal relationships between objects (Winn & Snyder, 1996). A delivery driver may run through his mental model of his route prior to the delivery, or an actor may rehearse a mental model of the scene she will be performing next.

The objective for designers of virtual environments for education is to help learners create a better mental model than they had prior to instruction. Virtual environments may enable learners to form good mental models by the inherent ability to view the spatial relationships between objects, the parameters of objects, and causal relationships between parts. According to Mayer (1989), a good conceptual model is complete, concise, coherent, concrete, conceptual, correct, and considerate. A good model is complete in that it presents all the parts and relationships among those parts, as well as the actions necessary for the learner to understand how the system being presented works. Good conceptual models are concise by having enough detail to provide understanding but not so much as to overwhelm or distract the learner, and coherent in that they are logical and intuitive to use. A concrete model is one that is presented in a way that is familiar to the learner and is conceptual by presenting meaningful information on the system being learned. Correct models relate closely to the real objects, systems, or events they are representing. A considerate model uses appropriate language and presentation for the learner.

Norman (1983) on the other hand claims that mental models do not need to be technically precise but should be functional. He defines mental models as internal representations formed by interacting with the environment, people, and objects. Once formed, they have predictive and explanatory power. According to Norman (1983), mental models continue to evolve over time as a person interacts with the environment and things in it.

Though not experiments on virtual environments directly, the following two studies offer insights into the manipulation of mental models that are applicable to virtual environments. Ives and Rakow’s (1983) study speaks to the benefits of explicit feature descriptions in spatial perspective and rotation tasks. Such data could be a good argument for detail or fidelity in virtual environments for spatial or rotation tasks or mental model formation. Seddon, Eniaiyeju, and Jusoh (1984) studied the problem of mentally rotating models of molecules. The use of a physical model was compared to the use of a physical model with shadows cast from it and the use of two-dimensional diagrams on paper as instruction prior to testing. Results showed that participants who used physical models performed significantly better, and the group who used physical models with shadows performed significantly better than the physical models alone. This information could be transferred to virtual environment design in regard to visual fidelity.

Billinghurst and Weghorst (1994) tested the usefulness of sketch maps in measuring learners' cognitive maps formed in virtual environments. Billinghurst and Weghorst tested for a correlation between orientation as recorded via a survey and sketch maps. They use the term *cognitive map* to mean a mental model of a spatial environment, including the locations and attributes of phenomena within it. A high positive correlation between orientation and sketch map accuracy was found. Thus, based on this study, sketch maps could be used as a measure of the mental model formed in a virtual environment.

Situated Learning and Meaningful Contexts

The situated learning model states that knowledge is situated within the context and activity that it is used. According to situated learning, knowledge must be learned in the real setting in which the to-be-learned activity will occur or the nearest possible approximation (McLellan, 1996). Virtual environments could provide this realistic approximation. McLellan (1996) reports that the critical components of situated learning exist in the Line-Oriented Flight Training program, including apprenticeship, collaboration, reflection, coaching, multiple practice, and articulation of learning skills. Learning in a virtual environment that is faithful to its real-world counterpart is more likely to transfer (Dede, 1992).

Multiple Intelligences

McLellan (1994) claims that virtual environments are capable of supporting each of Gardner's seven intelligences: spatial intelligence, bodily kinesthetic intelligence, logical-mathematical intelligence, musical intelligence, linguistic intelligence, interpersonal intelligence, and intrapersonal intelligence, each of which a normally developed person can attain a level of mastery in.

Spatial intelligence is the ability to visualize objects and spaces and mentally rotate objects. People with high spatial intelligence are good with visual details, can express ideas graphically, and are good at orienting themselves in three-dimensional space. Scientific visualization applications support spatial intelligence as well as logical mathematical intelligence. Virtual environments can display data in three-dimensions and allow users to view the data from multiple perspectives, observing relationships and interactions spatially. Architectural walkthroughs, training in route knowledge, and training on tasks involving the manipulation of objects are other spatial intelligence tasks supported by virtual environments.

Bodily kinesthetic intelligence is a person's ability to control their body and handle objects and is often reflected in hand-eye coordination and athleticism. Features of virtual environments such as haptic-feedback devices support bodily kinesthetic intelligence. Adding touch-feedback to data visualization of a complex concept such as electric fields (Salzman, Dede, Loftin, & Chen, 1999) provides another channel of communication with which the learner can gather information.

Logical-mathematical intelligence involves reasoning, logic, forming hypotheses, understanding cause and effect, conceptual regularities, and pattern recognition. McLellan explains that virtual environments can connect logical-mathematical intelligence to other intelligences, such as spatial and bodily kinesthetic intelligence. The ability to experience a phenomenon or concept (albeit in metaphorical form) brings these intelligences together to take advantage of humans' natural capabilities for making sense of the world. Project ScienceSpace (see p. 40) is an example of this linkage.

Musical intelligence is the perception, appreciation, and creation of patterns of pitch and rhythm. McLellan (1998) claims that three-dimensional positional sound systems support musical intelligence through applications that react to the user's input, such as the Very Nervous System, which is used for physical rehabilitation. By making different sounds based on users' different movements, the system helps motivate patients to persist through repetitive workouts.

Linguistic intelligence is skill with the understanding and use of spoken and written words. McLellan (1998) cites a telepresence application, the Electronic Café International, as a virtual environment that supports linguistic intelligence. Any collaborative virtual environment where users are communicating via text or speech (Johnson, Moher, Leigh, Vasilakis, & Barnes, 1999; Johnson, Rickel, Stiles, & Munro, 1998) supports linguistic intelligence.

Interpersonal intelligence is the ability to understand, collaborate, and work with other people. McLellan lists multiperson computer games and flight simulators involving pilot and copilot training together as examples of virtual environments supporting interpersonal intelligence. Collaborative applications, such as the Simulation Networking (SIMNET) military trainer, support interpersonal intelligence by emphasizing teamwork to successfully fulfill the training mission objectives.

Intrapersonal intelligence is the ability to know oneself and understand one's feelings. McLellan claims that role-playing computer games support intrapersonal intelligence by allowing users to view the virtual world from perspectives other than their own. Educational applications such as those in Project ScienceSpace and Virtual Puget Sound (Winn, Windschitl, & Thomson-Bulldis, 1999) allow users to assume the viewpoint of objects within the environment in addition to their own.

Virtual environments have the ability to make use of multiple intelligences and access them simultaneously to allow learners to interact with information in novel ways. Being able to interact with complex concepts such as Newtonian physics visually, aurally, and physically is perhaps one of the most compelling reasons to use virtual environments in education.

Social Learning

The (N.I.C.E) project is an example of virtual environments being used for social learning (Johnson, Moher, Leigh, Vasilakis, & Barnes, 1999). The project had children building their own persistent virtual worlds in the CAVE. The children worked together to build an ecosystem by deciding where to plant crops and how to care for them. The goal of the N.I.C.E. project was to use it as testbed for exploring virtual environments as a learning tool for constructivist learning, collaboration, and narrative development. Johnson et al. cite the lack of direction, combined with the novelty and difficulty the young students (second graders) had using the equipment, as interfering with the intended learning goals. The presence of avatars representing remote users improved social interaction but didn't help with cooperative learning. The socializing became an end, not a means to learning. The project led to the development of four recommendations for the future use of virtual environments as learning tools (p. 261):

1) the learning goals should be derived from important national standards;

2) the learning goal should be a difficult enough concept or mental model to require the use of virtual reality;

3) virtual reality should enhance the learning goal in some way;

4) virtual environment–based learning should be grounded in current learning research, practices in education, and the realities of school organization and funding.

Other social learning activities in virtual environments include Winn's (1999) project to link children in school with children in a hospital to collaborate in a shared world.

The Cognitive Style of Field Dependence

Witkin, Oltman, Raskin, and Karp (1971) define cognitive styles as "the characteristic, self-consistent modes of functioning that individuals show in their perceptual and intellectual activities" (p.3). Messick (1970) describes cognitive styles as dimensions of individual differences in the ability to perform cognitive tasks. This ability seems to be a consistent indicator of the way an individual goes about cognition, if not the level of cognition itself (1970). According to Witkin (1965), it is possible to objectively evaluate an individual's cognitive style through experimental procedures.

According to Messick (1970), cognitive styles are information-processing habits. Messick lists nine examples, which lie on a bipolar continuum: field dependence versus independence, scanning, breadth of categorizing, conceptualizing styles, cognitive complexity versus simplicity, reflectiveness versus impulsivity, leveling versus sharpening, constricted versus flexible control, and tolerance for incongruous or unrealistic experiences (1970). Of these, field dependence has been studied widely and measured reliably over time with various tests, including the rod and frame and embedded figures tests. Field dependence is operationalized as one's perceptual style or approach when confronted with a structure (Witkin et al., 1971).

The rod and frame test was part of Witkin's early work involving perception of the upright (Witkin et al., 1971). The body-adjustment and rotating-room tests were also used as measures of perception of the upright (Witkin et al., 1979). Participants who used visual cues as a reference for upright were termed field-dependent, while those who used an internal (or body) reference for upright were called field-independent.

Later, participants' ability to perceive the upright correlated strongly with their ability to disembed a figure from a complex background as measured by the embedded figures test. The object of the embedded-figures test was to pick a simple shape out of complex background. Witkin et al. later redefined field dependence as a "disembedding ability in perception" (1979, p. 1129). Disembedding ability has also been linked to one's ability to reverse perspective (Newbigging, 1954).

The ability to disembed in perceptual tasks has been associated with the ability to disembed in non-perceptual tasks, leading to the development of the concept of global versus articulated approaches to a field (Witkin, Goodenough, & Oltman, (1979). Encompassing both these constructs is the concept of differentiation. In relation to field dependence, the global-articulated dimension of cognitive functioning is conceptualized by Witkin et al. (1971) as an increase in the "articulation of experience" (p. 7) as field independence increases. In other words, articulation is one's ability to examine one's own experience and organize it. Persons who are field-dependent tend to have their experience structured by the field, whereas field-independent individuals are able to work past the presented organization of a field and create their own experience of it.

Differentiation is the broad psychological concept that field dependence and the global-articulated dimension fit within. Differentiation has broader reach than perceptual issues, including a person's self-identity, body concept and defense strategies. Commonalties in individuals' perceptual styles, articulation of experience, and differentiation functions indicate that the level of articulation of someone's experience is consistent regardless of that experience being from an external or internal source (Witkin et al., 1971).

Cognitive style theory holds that much information about an individual’s personal functioning can be ascertained from an examination of their cognitive behaviors (Witkin, et al., 1971). Field dependence is a continuum or dimension on which all people lie. The ends of the continuum, field-dependent and field-independent are relative to the sample being tested, and any sample will tend to distribute itself along a normal curve.

The ability to disembed has been shown consistent across other senses, including touch and hearing. Though performance at disembedding in a visual modality relates strongly with the ability to disembed in other perceptual modalities, it does not correlate with one’s general intelligence (Witkin et al., 1971).

According to Witkin et al. (1971), field-dependent individuals tend to perceive a visual field as rigid and without sub-parts. The overall organization, not the individual parts of the field, dominates their perception of that field. Field-independent individuals see the sub-parts of the visual field as separate from the overall organization of the field. Individuals who tend toward field-dependence do not perform as well as field-independent individuals at tasks that require taking an element from the context in which it is presented and using in a new way (1971).

Studies of perception of embedded figures have shown a significant difference in the amount of time required to disembed figures between males and females (Witkin, 1950). There is consistent evidence that a small difference in field dependence exists between boys and girls. In the United States and Europe, males have been shown to tend more toward field independence than females, though it appears the difference does not exist in young children and the elderly (Witkin et al., 1971).

Witkin et al. (1971) cite distinct changes in field dependence over one’s lifetime. Children show a steady trend toward field independence from the age of 8 to age 15. After the age of 15, increases in field independence level off, followed by a return toward field dependence in the elderly, with the greatest increase in return to field dependence occurring after age 30.

Survey of Virtual Environment Applications in Education and Training

Many applications of virtual reality for education involve Window-On-The-World environments displayed on the computer monitor, but there are examples of research into the use of immersive technologies such as HMDs and the CAVE for education in post-secondary and K–12 settings.

Some current applications of virtual environments include phobia treatment (Hodges, et al., 1995); instructional uses; entertainment; industrial, engineering and architectural design; and data visualization. The following is a brief survey of some current applications of virtual environments in education and training.

Applications in Education Settings

More desktop applications of virtual environments than immersive applications exist in education settings, possibly due to the cost involved with designing and supporting immersive virtual environments. What follows is a brief survey of immersive and non-immersive virtual environment applications in education settings.

Some uses for virtual environments in education include science education, design education, history, environmental education, literature, and special education. Several of the examples that follow are experiments conducted on applications for virtual environments in education settings.

Project ScienceSpace (Salzman, Dede, Loftin, & Chen, 1999) is composed of NewtonWorld, MaxwellWorld, and PaulingWorld, three virtual environments for science instruction. Development and evaluation of these projects is ongoing. The goal of Project ScienceSpace is to "identify, use, and evaluate immersive virtual reality's affordances as a means to facilitate the mastery of complex, abstract concepts" (p. 1). Students have difficulty in picturing and manipulating information in more than two dimensions, such as in math, science, engineering, statistics, and finance. This is similar to the problems students have with mentally rotating three-dimensional objects. These three projects are intended to help with these problems.

NewtonWorld is an immersive virtual environment intended to help learners enhance their understanding of and change common misconceptions about Newtonian physics. Sensory immersion is provided in the form of an HMD with stereo headphones and vibrating vest. Users are able to explore the environment, interact with the objects within it, and change their frame of reference among several cameras. And by being inside objects that are subject to forces, they can launch balls of different masses, observing the effects of kinetic and potential energies.

Three evaluations of NewtonWorld focused on the interaction experience, the learning experience, process, and outcomes as any tradeoffs among those factors. Two trials were held in addition to a survey of physics educators and researchers.

The findings of the first evaluation included that students felt that being able to change between several frames of reference was helpful in improving their understanding of the concepts presented. One problem created by attempting to improve usability was that students mistook the size of the objects in the world as an indicator of mass, which led to a faulty conception that larger objects have more mass. The study suggests that the ability to change frame of reference increases motivation during the learning process.

The second evaluation was a survey of physics educators and researchers. The participants were given a demonstration of NewtonWorld, then asked to fill out a survey on their interaction experience, thoughts on improving the virtual environment, and their feelings on the system's effectiveness for teaching Newtonian physics. The results showed this group felt that three-dimensional immersion, multiple frames of reference, and multisensory cues held promise for physics instruction (Salzman, Dede, Loftin, & Chen, 1999). The respondents felt that NewtonWorld was effective at demonstrating physics concepts and was easy to use.

The third evaluation of NewtonWorld investigated the affect of multisensory cues and multiple frames of reference on the interaction experience and the learning process and outcomes. Thirty high school students were assigned to three groups: visual cues only; visual and auditory cues; and visual, auditory and haptic cues. The students had at least one year of high school physics, and a pre-test showed that most had some difficulty with physics concepts such as velocity and acceleration. No significant difference was found between pre- and post-test scores or between groups. Salzman et al. (1999) cite the limited exposure to the environment as a possible explanation. Though nonsignificant, there were better scores among participants who received all three cues on the velocity and acceleration questions. The same participants performed worse on predicting the behavior of the system. It is possible that the haptic feedback caused the participants to pay more attention to the wrong information. Participants who received all three cues cited the egocentric perspective as more meaningful than participants who received only visual cues. This finding highlights the fact that the features of a virtual environment work in combination and must be carefully tested for their effects on learning.

MaxwellWorld is a lesson in electrostatics. The learner manipulates forces and fields in an immersive environment which, like NewtonWorld, makes use of multisensory cues including visual, auditory, and tactile cues. The learner can take the frame of reference of a test charge or release a test charge into the environment and observe the effects. Three frames of reference are currently being studied: egocentric, exocentric and bicentric, or both frames. The researchers predict that changing perspectives will highlight otherwise overlooked information and encourage more flexibility in the learners' thinking.

Two evaluations of MaxwellWorld focused on whether students could learn specific concepts in electrostatics and compared the immersive virtual environment to a popular two-dimensional computer program for learning about electric fields and electric potential (Salzman, Dede, Loftin, & Chen, 1999).

There was a significant difference between pre- and post-test scores among the high school and college students who participated in the study (Salzman, Dede, Loftin, & Chen, 1999). Participants cited the immersive environment, interactivity, multiple frames of reference, and use of color to represent different characteristics of MaxwellWorld as important to the learning process. Participants rated the learning experience as stimulating and the interaction technique as fairly easy to use.

The comparison between the two-dimensional and three-dimensional environments consisted of two separate treatments. The first had MaxwellWorld's feature set modified to use only those features for which the two-dimensional program had a similar feature. In the second, MaxwellWorld made use of all its features. In the first treatment, participants who used MaxwellWorld were better at defining concepts than those participants in the two-dimensional group. Participants reported that they were highly motivated by MaxwellWorld, though when isolated neither motivation nor meaningfulness were predictors of learning outcomes. In the second treatment, there was a significant positive difference in understanding concepts, two-dimensional sketches, and three-dimensional demonstrations in post-test scores. The examination of multisensory cues provided in the second treatment implied that those participants who had difficulty with the concepts benefited more from the multisensory cues.

PaulingWorld is an immersive virtual environment designed for chemistry instruction (Salzman, Dede, Loftin, & Chen, 1999). It is still under development but is intended to teach concepts that are not easily represented or difficult for students to grasp. The evaluation of PaulingWorld has not been published at this time, but it will include a measure of the sense of presence in addition to other measures such as motivation.

Salzman et al. (1999) claim that well designed immersive virtual environments that make use of multisensory displays might be able to help users understand concepts such as an electromagnetic field by allowing them to apply their natural ability to interact with the physical world to make sense of the information. They list three features of virtual reality as promising for learning applications: three-dimensional immersion, frames of reference, and multisensory cues. Immersion may help learners make more accurate mental models by making concepts more notable. Virtual environments allow the learner to change perspective, getting an overall view of what is happening or by becoming part of the phenomenon itself. Multisensory cues are provided by high-end virtual reality interfaces, allowing the learner to use the senses of sight, hearing, and touch to gather information and navigate through the virtual space. Though there is much information on how virtual reality might help people learn, the specific features or “affordances” that are the most effective for different types of learning are not as well researched. Project ScienceSpace is being used to specify what features work best for the learning of abstract concepts. This work has laid groundwork for future research in learning in virtual environments. By performing well designed studies on isolated variables, the research performed as part of Project ScienceSpace provides several areas from which future study can emerge.

At the University of Washington’s Human Interface Technology Laboratory (HIT Lab), a project is being developed where students will use immersive virtual environments to designate the best site for Seattle to build its new sewage treatment plant and the pipe that releases treated sewage into the sea (Winn, 1998). It is hoped that by performing this task in an immersive virtual environment, students will be able to experience the information in new and unique ways and, in turn, improve their scientific concepts related to oceanography, etc.

The Virtual Reality Roving Vehicles project (Rose, 1995) is another project of the HIT Lab, where students built their own virtual environments of wetlands. The students were split up into groups that worked on a different part of wetland ecology. When the virtual environments were finished, they were combined, and the students donned HMDs to explore the virtual environment. The students manipulated objects in the virtual environment that represented nitrogen and bacteria, enacting the nitrogen cycle. The objective of the project was to identify a paradigm for assessing learning in virtual environments. In the discussion of virtual environment experience factors, a need to understand how presence or immersion may effect learning is identified.

Gaddis (1997) describes an example of using virtual environments to increase literature students' motivation and to enhance their understanding of what they have read. After reading a story, students used a head-mounted display to explore a virtual environment based on the story and identify the elements of the virtual environment that did not appear in the story. No performance data was provided, but students' enthusiastic comments lead to the development of an entire course where literature was taught with virtual environments. Students were able to explore virtual environments based on works of literature read in the course. Finally, students presented a virtual environment that they built themselves based on a short story of their choice. No experimental results were provided.

Siddens (1999) describes several applications of virtual environments in education settings starting in the early 1990s at the West Denton High School in England. Three virtual environments were explored on laptop computers: a factory, a foreign city, and a park. "The Living Textbook" at Syracuse University included among other applications the ability to fly through a virtual environment of New York State, touring sites and landmarks of significance. Siddens goes on to describe projects at the Virtual Reality and Education Laboratory at East Carolina University, including history, literature, atomic modeling, electromagnetic studies, and programs for learning disabled children.

Other work in applying virtual environments to special education include the virtual classroom at the HIT Lab, where students in a conventional classroom in Seattle collaborate with students at Children's Hospital in a virtual environment to learn about global warming (Winn, 1999b). Other work in the area of virtual environments in special education include Neale, Brown, Cobb, and Wilson's (1999) work to develop evaluation methods for virtual environments designed for children with severe learning difficulties.

Bowman, Wineman, Hodges, and Allison, (1998) developed a virtual environment for students in an environmental design course. Students were tasked with designing an animal habitat for Zoo Atlanta in an immersive virtual environment. All design work was performed while immersed using a head mounted display. Experiments with a series of interaction techniques were conducted. While the results were inconclusive, interesting insights into immersion as a variable in a learning task emerged. Students reacted negatively to being constantly immersed in the habitat during design (Bowman, Hodges, Allison, & Wineman, 1999).

The Virtual Solar System is an astronomy course where students build a scale model of the solar system in VRML, then view their models in the CAVE (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 1999). Medical students are using three-dimensional visualization to improve their skills in clinical evaluations (Hallgren & Gorbis, 1999). All educational virtual environment applications are not immersive, however. The ExploreNet project (Hughes & Moshell, 1994) is a desktop-based, multi-user virtual environment intended to encourage cooperative problem solving in math, social studies, and science.

Applications in Training Settings

Training in the military and industry has made use of virtual environments for 30 years, dating back to flight simulators in the 1960s. Training applications span from desktop to a complex vehicle simulator. The following is a brief look at several current virtual environment applications in training settings that cover the entire range from desktop to simulator, including military training (OTA, 1994), firefighter training (Bliss, et al., 1997), and equipment procedures training (Hamel & Ryan-Jones, 1997).

Dorner, Schafer, Elcacho, and Luckas (1998) explain how VRML can be used in training settings and describe how a VRML authoring tool they have developed can be applied to such settings. Dorner et al. list potential uses such as safety, repair, and new product training, citing VRML's ease of development, low cost, and efficient integration into the World Wide Web as benefits of its use.

Hubal, Helms, and Triplett (1997) describe the Advanced Learning Environment (ALE) model as an integration of virtual environments and other multimedia technologies for use in training settings. The ALE is a process to be used for the planning and design of training, encompassing everything from methodologies of instruction to facility management. At the time of the writing of this paper, Hubal et al. were performing an experiment in a military training setting to evaluate the effectiveness of virtual reality in training versus a traditional approach.

In their overview of the Virtual Training Program at Fort Knox, Schlecter and Burnside (1996) give a description of the SIMNET virtual environment training system. They provide an assessment of the SIMNET program and lessons learned. Their commentary centers on instructional procedures related to simulator training for multiple participants in a shared virtual environment. They cite the structured instructional program at the Virtual Training Program as the key to the successful application of the SIMNET technology.

The promise of virtual environments as a safe alternative for training is described in Hadipriono's (1996) report on the Safety in Construction Using Virtual Reality training program. Learners were immersed in a virtual environment and performed on-the-job training activities focusing on work site safety. Learners were tasked with either erecting scaffolding on a worksite or inspecting scaffolding previously set up on a work site. Learners identified problems to earn points in an overall score. Due to the complexity of the models in the environment, this training application required the use of supercomputers.

Johnson, Rickel, Stiles, and Munro (1998) introduced a virtual training expert named Steve (Soar Training Expert for Virtual Environments) into a virtual environment to aid learners in unfamiliar situations. The Steve system makes use of complex artificial intelligence technology to allow Steve to model behaviors and teach. The first application of Steve was in training for the use of a high-pressure air compressor. The application can be used in either an immersive environment or a desktop environment. Students can watch Steve demonstrate the procedures for using the equipment while he speaks to them. Students are also able to ask Steve questions and receive context-based responses.

Survey of Experiments in Virtual Environments for Instruction

Understanding what effect features of virtual environments have on learning outcomes would facilitate the systematic design of virtual environments for assisting users in meeting learning goals. At the same time, insight into how learner characteristics interact with the characteristics of virtual environments may be of equal importance. The following survey of virtual-environment experiments in the area of instructional uses shows little research in the area of individual characteristics and the non-xistence of investigation into the effects of learners' field dependence on learning in virtual environments.

In a survey-based study seeking an understanding of principles involved with instructional virtual environments, Dennen and Branch (1995) asked participants from instructional design, computer science, and media for their perceptions of virtual reality in education. Participants were asked for a definition of virtual reality, how they felt virtual environments should be designed for learning, who should design virtual environments, and how they felt instructional virtual environments should be evaluated.

Among the conclusions, participants felt that immersion did exist along a continuum, that computer simulation is not immersive enough to be called virtual reality, and that full immersion is not essential for learning in virtual environments. Dennen and Branch conclude that the level of immersion should be chosen based on the application and suggest more study into what features of virtual environments are most useful for learning.

Taylor (1997) studied the reactions of students in grades 4–12 to immersion in a virtual environment using an HMD. Taylor sought to examine the relationship between the participants' rating of the feeling of presence with their enjoyment of the experience, ability to navigate the virtual environment, and ability to perform tasks in the virtual environment.

Participants rated the virtual environment highly for enjoyment and reported a high degree of presence. Ease of navigation was skewed positively, while the ratings for difficulty working in the virtual environment and seeing objects in the virtual environment were more evenly distributed. Further questions regarding disorientation and queasiness were skewed toward less queasy and less disoriented. Based on these findings, Taylor concludes that virtual environments are appropriate for classroom use.

A study by Waller, Hunt, and Knapp (1998) showed that long-term training for route knowledge in an immersive virtual environment might be superior to training with a map and showed no significant difference from such training in the real world. The study also showed that though training in a low-fidelity (a subjective perception of the virtual environment's similarity to the real world) virtual environment allowed participants to make usable mental models of the virtual space, short-term exposure to the virtual environment showed no more effectiveness than traditional map training. Additionally, in such a short-term exposure, immersive virtual environments may be no more effective than such training delivered via a desktop virtual environment.

Participants were assigned to groups for training in six different environments: no training, real world, map, virtual environment desktop, virtual environment immersive, and virtual environment long immersive (longer time in virtual environment). They were then asked to navigate a real maze based on the training. Waller et al. define fidelity as how much the appearance and interaction with a virtual environment mimics a real environment. In a similar study, Witmer, Bailey, and Knerr (1996) successfully used a virtual environment with no tactile feedback or sound to test learners' transfer of route knowledge from a virtual environment.

Waller et al. (1998) describe information domains in virtual environments: the real-world environment, the training environment, and the mental representation of the environment. Environmental fidelity is the mediator between the training environment and real environment. Interface fidelity is the mediator between the virtual environment and the mental environment.

Environmental fidelity is a psychological concept about the degree to which objects and places resemble their real-world counterparts. Interface fidelity is a measure of how much the inputs and outputs in a virtual environment are like those used in the real world. Waller et al. organized interface devices into two treatment groups: an immersed condition and a desktop condition. The immersed condition used an HMD and head tracker. The desktop condition used a 21-inch monitor. Importantly, navigation was handled by a four-degree-of-freedom joystick in both conditions, thereby controlling for the confounding effect of the differing interaction techniques.

When becoming familiar with a new environment, a person first picks out the important landmarks in the environment (Waller, Hunt, & Knapp, 1998). No relationship between the landmarks is made at this point. After more time in the environment, it is possible to link the landmarks together into routes or a route representation. Further time in the environment allows some to create a map-like model called a survey representation or configurational knowledge. A survey representation of a space contains the spatial relationships between landmarks independent of the routes between them (Waller, Hunt, & Knapp, 1998).

Though imperfect, survey knowledge contains a better understanding of the spatial qualities of an environment than route knowledge. People must make a conscious effort to form survey knowledge. The fact that virtual environments have a limited field of view and that the interface is not intuitive for many people makes forming a survey representation in a virtual environment more difficult than in real environments. To control for the increased cognitive load getting in the way of learning, Waller, Hunt, and Knapp (1998) measured participants' survey representation across six points.

The main measure was blindfolded navigation of a physical maze made up of curtains following training in the same maze in the six different treatments. The measure was chosen because it requires an accurate mental model of the space and measures spatial behavior as well, forcing the participants to rely heavily on the training they received.

Six independent variables were used: blindfolded training, real maze, paper map, immersive virtual environment, long-time immersive virtual environment, and desktop virtual (Waller, Hunt, & Knapp, 1998). Time to successfully navigate the maze was the dependent variable, and it was found that all participants' performance improved over the six trials. The rate of improvement depended on the type of training. The treatment consisted of one minute of training for the real-world group, and one minute of training for the map group. Two minutes of training were given to the desktop virtual environment group, two minutes of training for the immersed virtual environment group, and five minutes of training for the long-duration immersed virtual environment group. No previous exposure to the maze was provided for the blindfolded group. All groups except the blind group were shown the correct route through the maze during the training.

After two trials, the real-world group performed significantly better than the other groups (Waller, Hunt, & Knapp, 1998). The mean for all the virtual environment groups to navigate the maze (270.51 seconds) was worse than the real-world group (mean of 163.32 seconds to complete the maze) and map group (mean of 242.88 seconds to complete the maze) after the first two trials. By the second trial, the immersive virtual environment long-immersive group (which received five minutes of training) had a lower mean time to complete the maze (122.05 seconds) than did the map group (191.70 seconds).

Comparing the immersed group to the non-immersed virtual environment group yielded no significant difference over the first two trials (Waller, Hunt, & Knapp, 1998). Comparing the three different virtual environment training-groups to the map group also showed no significant difference. However, by the sixth training session, the long-duration immersive group (40.95 seconds) performed better than the real-world training group (56.5 seconds), though not significantly. Scores on a true-false measure asking whether a specific map correctly represented a portion of the maze showed that for both genders, map training resulted in the best performance and the two-minute immersed group showed the worst performance, not considering the blindfolded group. This may be due to the practice most closely resembling the assessment.

Waller et al. (1998) concluded that a relatively low-fidelity virtual environment can allow people to develop usable representations of a large-scale navigable space. Short exposure to virtual environment training does not appear to be any better than map training. Long-term training in an immersive virtual environment may be better than map training and indistinguishable from real-world training on tasks that require route knowledge. Waller et al. (1998) pointed out that the restricted field of view in an immersive virtual environment and the increased cognitive load might have prevented the development of survey understanding. They concluded that virtual environments can be effective for training on spatial knowledge and that fidelity has little effect on success in a route knowledge task.

The sense of presence is subjective, differing from individual to individual. Prothero, Parker, Furness, and Wells (1995) developed a measure for presence, including a series of experiments for objectively measuring presence. They suggest that presence and vection, a sense of self-motion brought about by visual cues, are closely related, and that both may be a result of “spatial adaptation.” No results of experiments were found. Measuring presence is one thing, but measuring presence or immersion’s role in learning is another entirely.

Gunawardena and Zittle (1997) studied the degree to which social presence is a predictor of learner satisfaction in a text-based conferencing environment. Fifty students from five universities participated, and the results suggest that social presence is a strong predictor of satisfaction in a text-based computer conferencing environment, accounting for 60% of the variance in satisfaction. Gunawardena and Zittle concluded that the way students perceive the social qualities of computer-mediated communication will be dependent upon the existence of social presence as formed by the instructors and other participants in the experience.

Witmer and Singer’s (1998) presence questionnaire has been used to examine factors in the sense of presence in virtual environments. Witmer and Singer developed a presence questionnaire and an immersive-tendencies questionnaire to measure the correlation between participant-reported presence and other variables. Based on four separate experiments, a weak but positive correlation between sense of presence and task performance in virtual environments emerged. Also, the immersive-tendencies questionnaire was found to be a reliable predictor of presence, as reported in the presence questionnaire.

Slater (1999) expresses doubt in Witmer and Singer’s report of a positive correlation between presence and task performance on the basis that the results of Witmer and Singer’s four experiments were inconclusive in this regard. Slater goes on to suggest that the immersive-tendencies questionnaire is the preferred method for measuring presence because it measures an individual’s characteristics. He suggests that ethnography would result in quality insights into presence, though questionnaires are more suitable to quantitative research.

Welch (1999) finds the inference of causality in the presence to task performance relationship suspect as well. He feels that though there are measures of presence in use, no evidence exists that the correlation indicates causality. Welch goes on to describe a series of experiments, including a completed pilot study, designed to unconfound other variables of presence, and look for a causal relationship between presence and task performance. The pilot study used presence of sound as the independent variable because sound has been cited as a factor enhancing presence, and task performance as the dependent variable. No significant difference in task performance was noted, but the author suggests that the presence created was relatively weak, so the findings of the pilot study should not be taken as a definitive finding.

Winn, Windschiti, and Thomson-Bulldis (1999) are developing research into what features of immersive virtual environments affect scientific concept acquisition enough to justify the cost and development of immersive virtual environments for such science education applications. The focus of their research will be in comparing immersive and non-immersive simulations to improve students' concepts of complex environmental processes. One part of the research will use immersive and non-immersive simulations to teach college undergraduates about the Puget Sound environment. The second part of the research will examine the effect of immersive and non-immersive simulations on high school students' conceptions, misconceptions, and changes in conception of the environment. This is the best example of current research into the question of immersion's effect on learning, and when the extra cost and development of immersive virtual environments can be justified.

Though not a study in virtual environments, Choi (1998) performed a study on fidelity in an economics simulation. In his study, he defines fidelity as the number and flexibility of actions allowed in the simulation, not as a visual attribute. Choi found no significant difference in the level of fidelity on the participants' performance using the simulation.

Boyd (1997) claims that participants performed better in a search and navigation task using an immersive interface than when using two non-immersive interfaces. Each treatment used a different interaction technique for locomotion, which could confound the immersion variable and account for a significant portion of the variance in performance.

Payne and Jones' (1999) comparison of immersive versus non-immersive displays had participants use an HMD or desktop to navigate buildings in a virtual environment. Different interaction techniques, a wand in the immersive group versus a keyboard and mouse in the desktop group, were used. Though not a significant main effect, participants using the HMD navigated the building 12% more quickly but did not travel a shorter distance using the HMD.

There are many viewpoints on what works best in virtual environments. Researchers cite constructivism, experiential learning, social learning, mental model theory, situated learning and meaningful contexts, and multiple intelligences as learning theories or models that virtual environments can exploit. Learning goals that stand out as viable applications of virtual environments for instruction include guided exploration of a virtual space, the development of mental models, and complex concept understanding. One of the strengths of a virtual environment is the ability to transport the user to a place they cannot physically go or observe and manipulate phenomena that are not accessible to human perception.

Investigation of learner characteristics is an overlooked area of research in virtual environments that is ripe for further study. The many features of virtual environments interact in complex ways to affect the learning process and learning outcomes. But it is likely that individual characteristics also interact with the features of virtual environments to effect learning outcomes. Salzman, Dede, Loftin, and Chen's (1999) work with learners' frames of reference indicates an interest in the effect of learner characteristics on learning outcomes. The field-dependence construct is a natural fit study in virtual environments due to the heavy emphasis on the acquisition and processing of visual information.

Variables of Interest

Little research has been conducted on how learner characteristics and the features of virtual environments interact to effect learning. Understanding the effects of learners' field dependence on learning in virtual environments could result in the design of virtual environments that work better for field-dependent learners while not negatively effecting field-independent individuals. It may be that one's ability to disembed objects from a visual field is more important for learning in a virtual environment than the realism of the virtual environment itself. It may also be that more complex concepts or images are not well suited to virtual environments used by field-dependent learners, resulting in a negative effect on such individuals' understanding of the concept presented.

The individual characteristic of field dependence seems a natural fit for research in virtual environments as learning tools because of the emphasis on the acquisition and processing of visual information in such an experience. It is with this in mind that the variables of interest in this study are field dependence and image type, two-dimensional versus three-dimensional.

There are several reasons that the use of virtual might influence field dependence. Salzman, Dede, Loftin and Chen (1999) state that characteristics of virtual environments may influence learning processes and, thus, the learning outcomes. In Salzman et al.'s (1999) model of concept learning in virtual environments, this research fits in the central segment on learner characteristics. Salzman et al. (1999) list spatial ability, gender, domain experience, computer experience, motion-sickness history, and immersive tendency as some learner characteristics. This study proposes that the cognitive style of field dependence fits among these variables.

Among Winn and Jackson's (1999) propositions for learning in virtual environments are the notions that virtual environments allow a somewhat natural interaction with objects that we might otherwise not be able to interact with, and that virtual environments are most effective when changes in three-dimensional viewpoint contribute to learning. This change in three-dimensional viewpoint may assist field-dependent learners in breaking the figure-ground linkage. Having the ability to rotate an object and investigate it from different viewpoints could be the most helpful aspect of virtual environment for field-dependent learners. According to Winn and Snyder, (1996) virtual environments can help in the formation of mental models, and mental model theory is not limited to spatial knowledge but includes perception of the causal relationships between objects. The understanding of causal relationships could assist in comprehension of complex concepts.

Significance of the Study

The purpose of this study is to provide data on the effect of virtual environments on the recall of field-dependent participants. Existing research in field dependence and virtual environments has not compared the effectiveness of virtual environments for field-dependent learners. Desktop virtual reality allows the low cost and widespread use of virtual environments for instructional purposes. A three-dimensional model of an object using Virtual Reality Modeling Language (VRML), a Web browser, and Internet connection are all that are needed to utilize such an approach to displaying images.

What desktop virtual reality gives up in presence and immersion, it gains back in accessibility. Such technology is available in many secondary schools and most colleges and universities. The findings of this study are therefore applicable to the widest possible population. The use of virtual reality as a learning tool is gaining support, and research into improving the technology for learning applications is widespread. However, research into making best use of the technology to help the widest spectrum of learners by investigating the effects of individual differences is less prevalent. This study seeks to add to the understanding of learner characteristics' effect on learning outcomes in virtual environments.

Research Questions and Hypotheses

The general research question that emerged from the literature on learning in virtual environments and field dependence-independence concerns whether the use of virtual environments has an effect on field-dependent participants' performance in a test of recall. As outlined previously, virtual reality systems take many shapes and sizes. Desktop virtual reality most closely resembles the delivery mechanism of two-dimensional images by using the same delivery mechanism as images on a Web page.

The only difference in images in this study is that the virtual environments show the shape and contour of the object in three dimensions, and participants can rotate the image to investigate it from different viewpoints.

In order to examine the effect of virtual environments on recall among learners of differing levels of field dependence, the following specific questions and hypotheses were formed:

1) Does the use of virtual environments affect participants' performance in a task of recall?

2) Do participants of different levels of field dependence perform differently on a task of recall when presented with virtual environments versus static images?

3) Do field-dependent participants score higher on a test of recall when presented with a virtual environment?

Experimental Hypotheses

The research questions presented are investigated through the use of an experimental design. Participants' ability to rotate the image in the virtual environment and observe it from different viewpoints might help field-dependent participants in disembedding the image; therefore it was expected that there should be higher test scores for those participants versus field-dependent participants receiving the static-image treatment.

H_1: Test scores for participants in the virtual environment treatment condition will be higher than test scores for participants in the static-image treatment condition.

H_2: Test scores for field-dependent participants in the virtual environment treatment group will be higher than test scores for field-dependent participants presented with static images.

H_3: Field dependence interacts with the dimension of image type (static image versus virtual environment).

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

CHAPTER 3: METHODOLOGY

This chapter outlines the approach used to answer the research questions in this study, detailing the experimental design, participants, instruments, procedures, and analysis. Human subjects testing approval was obtained for this study. The experiment made use of an online computer program that displayed text, and two- and three-dimensional graphics and collected performance outcomes for each participant.

Experimental Design

A post-test-only design was used to determine if the treatment resulted in the variance in test scores. A 2 X 2 factorial design was used with main effects for two levels of field dependence (field dependent and field independent) and two levels of representation (virtual environment versus static images), and interaction effects between the two factors.

		Field Dependence	
		Field Dependent	Field Independent
Image Type	Virtual Environment		
	Static Image		

Figure 2. Experimental group assignment.

Human Subjects Testing Approval

Human subjects testing approval was granted for exempt status by the Virginia Tech Institutional Review Board effective January 31, 2002. A pilot study was performed to provide formative evaluation of the instruments and procedures. Changes made as a result of the pilot study were performed prior to the first test session. Experimental trials began on February 12, 2002.

Participants

The sample was drawn from students enrolled in undergraduate and graduate courses at Virginia Tech. The sample consisted of both males and females18 years and older. A total of 100 participants took part in the study. Of that number, seven were excluded due to prior knowledge or problems with the Group Embedded Figures Test.

Instruments

In order to gauge participants' level of field dependence, the Group Embedded Figures Test (GEFT), based on the Embedded Figures Test (EFT), was administered. Further discussion will refer to the EFT, but the GEFT functions the same, only for a group setting. The EFT measures the ability to break up an organized visual field and separate it from that organized field. According to Witkin, Oltman, Raskin and Karp (1971, p. 3), "The subject's task on each trial is to locate a previously seen simple figure within a larger complex figure, which has been so organized as to obscure or embed the sought-after simple figure." Embedded Figures Test performance has been correlated with performance in other tasks that require disembedding a structure from a visual field, though not with a person's general intelligence (Witkin, et al., 1971). The GEFT has shown a reliability estimate of .82 for males and females alike, as measured by the Spearman-Brown reliability estimate (Witkin et al., 1971).

Witkin et al. (1971) state that scores on the EFT have been shown to be consistent with two previously used tests for field dependence-independence, the rod-and-frame test (RFT) and the body-adjustment test (BAT). The RFT had an individual seated in a dark room adjust the orientation of a luminous rod, which was aligned with a tilted luminous box to the vertical. The lighted box stayed in its original orientation. In the BAT, the individual was seated in a tilted room and asked to align him or herself upright while the room remained tilted.

The instructional unit was delivered via a dynamic Web site. The instructional unit is a modification of the 2000-word instrument on the human heart created by Dr. Francis M. Dwyer (Dwyer & Moore, 1992). Permission to modify the instructional content was granted by Dr. Francis M. Dwyer on October 23, 2001. A Web site for each of the two treatments took participants from the instructional phase to the testing phase.

The instruction was a 21-page Web site with text accompanied by images of the human heart in one of two formats. The first page of each treatment consisted of instructions for the use of the materials. Each treatment differs only in the image type used. The experimental treatment used a virtual environment of the human heart. The primary difference between the virtual environment treatment and the static-image treatment was that participants could rotate the heart to different viewpoints in the virtual environment. Participants assigned to the experimental treatment were informed that the image of the human heart could be rotated. The control treatment utilized static images that could not be rotated. In both treatments, each page loaded with the image of the heart oriented in the same manner (see Appendix V). A participant in the static-image treatment group would see the same image as a participant in the virtual environment group initially; the participants in the virtual environment group had the ability to rotate the heart image in any way they chose after the image loaded.

A time limit of 25 minutes was used for the instruction phase. Feedback from participants in the pilot study was used to determine that 25 minutes would be enough time for the majority of participants to complete the materials. The time limit was used to control for time spent on the instructional material as a confounding variable.

The participants received one of two tests depending on the treatment they were assigned to. Each test consisted of a 40-item, multiple-choice test with two measures for identification and terminology based on the instructional unit on the human heart. The tests differed only in the images provided for the identification portion. The control treatment used the two-dimensional images just as the instructional unit did, while the experimental treatment used a virtual environment.

The identification test consisted of 20 multiple-choice questions requiring the participant to identify numbered parts of the heart on the image provided. The identification test measured participants’ ability to tell one structure from another and relate the names of the parts of the heart with the specific structures (Dwyer & Moore, 1992). The reported Kuder-Richardson-21 reliability coefficient for the identification test is .80. The terminology test is comprised of 20 multiple-choice items testing the participants’ knowledge of facts and definitions of heart parts and function. The reported

Kuder-Richardson-21 reliability coefficient for the terminology test is .83 (Dwyer & Moore, 1992).

The experiment trials took place in the Center for Instructional Technology Solutions in Industry and Education's computer laboratory. 20 Microsoft Windows™–based PC workstations were used. The computers were identical in hardware and setup. Every other computer had the same treatment loaded, such that participants chose to seat themselves wherever they desired.

Procedures

Upon volunteering for the study, participants were provided with a Web site to choose a session that was convenient for them. The 12 sessions were pre-assigned a treatment, such that the participant was unaware of what treatment they would receive.

Upon arrival at the experimental session, each participant was given a GEFT booklet. Participants sat themselves randomly and were given the option to voluntarily retire from the study at any time. The format and purpose of the study were then explained.

After the introduction, participants were asked to indicate if they had prior knowledge of the material that was about to be presented. The Group Embedded Figures Test was then explained. Upon completion of the GEFT, the participants were asked to enter the number from their GEFT booklet into the entry screen of the computer program. The treatment phase of the experiment was explained, and the participants were informed that they could raise their hand to ask a question at any time. The treatment was then administered. Participants were given a maximum of 25 minutes to view the material on the heart, followed by an unlimited time to complete the multiple-choice test. Upon completion of the test, participants were thanked for participating and allowed to leave.

Data Analysis

Data for this study consisted of GEFT scores in paper booklets and performance measure scores stored in a database for each participant. Participants' GEFT booklets were scored and appended to the corresponding record of criterion measure scores.

Participants' scores were divided into groups along the field-dependence dimension for classification and measurement. Participants one-half standard deviation above the mean were considered field-independent, while participants one-half standard deviation below the mean were considered field-dependent (Dwyer & Moore, 1992). Scores that fell within one-half standard deviation of the mean were considered field-neutral but excluded from the analysis as detailed in the next chapter. A factorial analysis of variance was then used to analyze the test data in this study to compare means for field dependence and performance, as well as interaction effects.

CHAPTER 4: RESULTS AND CONCLUSIONS

This chapter presents the results of the study and conclusions drawn from those results. Means for subtest scores and the overall score as well as factorial analysis results are presented for each research hypothesis. Discussion of those results is followed by conclusions.

The purpose of this study was to provide data on the effect of different modes of image presentation on the recall of field-dependent participants. The general research question that emerged from the literature on learning in virtual environments and field dependence-independence concerns whether the use of virtual environments has an effect on field-dependent participants' performance in a test of recall. The study was designed to answer the following specific questions:

1) Does the use of virtual environments affect participants' performance in a task of recall?

2) Do participants of different levels of field dependence perform differently on a task of recall when presented with virtual environments versus static images?

3) Do field-dependent participants score higher on a test of recall when presented with a virtual environment?

The instrument used in this study required participants to take a test of disembedding ability, the Group Embedded Figures Test (GEFT), to determine their level of field dependence. After the GEFT was administered, the participants read a Web site with text and graphics, presenting information on the parts and function of the human heart. Following the first two tasks, participants took a 40-item test of recall consisting of two parts, a 20-item identification test and a 20-item terminology test.

The data was prepared for analysis by categorizing participants as field-dependent or field-independent via the same process used in Dwyer and Moore's study (1992). Scores were collected for 100 participants, of which 93 usable data points were obtained. Seven participants' scores were excluded from the study due to extensive prior experience with the human heart or problems with the GEFT.

The GEFT score grand mean was 13.344, with a standard deviation of 4.244 and a standard error of .440. Participants whose scores were one-half standard deviation below the mean for the group were classified as field-dependent, while participants whose scores were one-half standard deviation above the mean were classified field-independent. Twenty-nine (29) participants were classified as field-dependent with scores between zero to 11. Seventeen (17) participants were classified as field-neutral with GEFT scores greater than 11 but less than 15. This group of scores did not contribute significantly to the variance was excluded from further analysis. Forty-seven (47) participants were classified as field-independent with scores between 15 and 18. Between the two treatments, 42 participants received the virtual environment treatment, and 34 participants received the static-image treatment.

Means and standard deviations were generated for the scores, followed by a factorial analysis. A 2 X 2 ANOVA (two levels of field dependence and two levels of treatment) was used for the factorial analysis. The results of the analysis are presented in the next section with the related research hypotheses.

Results of Analysis

The following tables report the means and standard deviations for test scores for the terminology test (Table 1), identification test (Table 2), and the combined overall score (Table 3).

Table 1

Means and standard deviations for the terminology test

		Cognitive Style	
Treatment		Field Dependent	Field Independent
Static Image	M	10.667	10.947
	SD	3.848	4.116
	n	15	19
Virtual Environment	M	10.143	13.964
	SD	4.589	4.384
	n	14	28

For the terminology test, there was a significant difference in scores favoring field-independent participants as a result of the factorial ANOVA (Appendix III): $F (1, 72) = 4.100$, $p < .05$. A comparison of treatment resulted in no significant difference: $F (1, 72) = 1.514$, $p > .05$ (Appendix III) and no interaction between field dependence and treatment type: $F (1, 72) = 3.055$, $p > .05$ (Appendix III).

Table 2

Means and standard deviations for the identification test

		Cognitive Style	
Treatment		Field Dependent	Field Independent
Static Image	M	11.600	11.474
	SD	4.171	4.647
	n	15	19
Virtual Environment	M	11.357	14.607
	SD	3.153	2.936
	n	14	28

For the identification test, there was no significant difference in scores for field dependence as a result of the factorial ANOVA (Appendix II): $F (1, 72) = 3.121$, $p > .05$. Similarly, the main effect of image type yielded no significant difference: $F (1, 72) = 2.672$, $p > .05$ (Appendix II), nor was there an interaction between treatment and field dependence: $F (1, 72) = 3.646$, $p > .05$ (Appendix II).

Table 3

Means and standard deviations for the overall score

		Cognitive Style	
Treatment		Field Dependent	Field Independent
Static Image	M	22.267	22.421
	SD	6.798	7.960
	n	15	19
Virtual	M	21.500	28.571
Environment	SD	6.779	6.785
	n	14	28

For the overall scores, a comparison of scores through factorial ANOVA for field-dependent and field-independent participants shows a significant difference in scores favoring field-independent participants: $F(1, 72) = 4.576$, $p < .05$ (Appendix IV). No significant difference for the main effect of treatment was found: $F(1, 72) = 2.540$, $p > .05$ (Appendix IV). Finally, a significant interaction favoring field-independent participants who received the three-dimensional treatment was found: $F(1, 72) = 4.193$, $p < .05$ (Appendix IV).

The following is a summary of the results in relation to each of the three research hypotheses. Each hypothesis is presented with the associated means for test scores and results of a factorial analysis of variance, followed by a discussion of the results for each hypothesis.

H_1: Test scores for participants in the virtual-environment treatment condition will be higher than test scores for participants in the static-image treatment condition.

Participants who received the static-image treatment scored lower (Mean = 10.824, Standard Deviation = 3.943, Standard Error = .676) on the terminology test (Table 1.) than participants who received the virtual-environment treatment (Mean = 12.690, Standard Deviation = 4.760, Standard Error = .734). However, the results of the factorial ANOVA for the terminology test (Appendix III) for the main effect of image type indicate that this difference is not statistically significant: F (1, 72) = 1.514, p > .05.

As in the terminology test, participants who were in the static-image treatment condition scored lower (Mean = 11.529, Standard Deviation = 4.378, Standard Error = .751) on the identification test (Table 2.) than did participants in the virtual environment treatment (Mean = 13.524, Standard Deviation = 3.351, Standard Error = .517). Again, the factorial analysis of variance for the identification test (Appendix II) for the main effect of image type shows no significant difference: F (1, 72) = 2.672, p > .05.

The overall score (Table 3.) for participants who received the static-image treatment condition was lower (Mean = 22.353, Standard Deviation = 7.360, Standard Error = 1.262) than the overall score for participants who were in the virtual-environment treatment condition (Mean = 26.214, Standard Deviation = 7.501, Standard Error = 1.157). However, the factorial ANOVA for the overall scores (Appendix IV) for the main effect of image type indicate that this difference is not significant: F (1, 72) = 2.540, p > .05.

The literature has shown that virtual environments have promise in visualization, conceptual, and experiential tasks (Osberg, 1993; Salzman, Dede, Loftin, & Chen, 1999; Winn & Jackson, 1999; Winn, Windschiti & Thomson-Bulldis, 1999). The results of this study do not support the hypothesis that a virtual environment as presented through a Web page will aid participants in achieving higher scores on a test of recall.

It was hypothesized that the virtual environment treatment would yield higher test scores. Though the mean scores for the virtual-environment treatment condition were higher for the terminology and identification tests as well as the overall score, as analyzed through factorial analysis the differences were not statistically significant at the .05 level.

The difference between the mean scores for the terminology test for the static-image treatment group (M = 10.824) and the virtual-environment treatment group (M = 12.690) was not significant. Similarly, the difference for the static-image group (M = 11.529) and virtual-environment treatment group (M = 13.524) on the identification test was not statistically significant. The means for the overall score (22.353 and 26.214 for the static-image and virtual-environment treatment groups respectively) was higher in favor of the virtual-environment treatment group, though not significantly according to the factorial analysis.

H_2: Test scores for field-dependent participants presented with virtual environments will be higher than test scores for field-dependent participants presented with static images.

Field-dependent participants scored slightly lower using the virtual-environment treatment condition on each subtest as well as for the overall score. The scores on the terminology test (Table 1.) for field-dependent participants receiving the static-image treatment condition were higher (Mean = 10.667, Standard Deviation = 3.848, Standard Error = .994) than the score for the field-dependent/virtual-environment treatment condition group (Mean = 10.143, Standard Deviation = 4.589, Standard Error = 1.226). Results from the factorial ANOVA for the terminology test (Appendix III) indicate that the difference between scores on the two treatments for field-dependent participants is not significant: $F(1, 72) = 3.055$, $p > .05$.

On the identification test, the scores (Table 2.) for field-dependent participants who received the static-image treatment were higher (Mean = 11.600, Standard Deviation = 4.171, Standard Error = 1.077) than the scores for field-dependent participants in the virtual-environment treatment group (Mean = 11.357, Standard Deviation = 3.153, Standard Error = .843). Results of the factorial analysis for the identification test (Appendix II) indicate the difference between scores on static-image treatment and virtual-environment treatment for field-dependent participants was not significant: $F(1, 72) = 3.646$, $p > .05$.

The overall score (Table 3.) for field-dependent participants in the static-image treatment group was higher (Mean = 22.267, Standard Deviation = 6.798, Standard Error = 1.755) than the mean score for field-dependent participants in the virtual-environment treatment group (Mean = 21.500, Standard Deviation = 6.799, Standard Error = 1.812). However, the results from the factorial analysis for the overall scores (Appendix IV) indicate the difference between scores on static-image treatment and virtual-environment treatment for field-dependent participants is not significant: $F(1, 72) = 4.193$, $p > .05$.

The desired outcome for this hypothesis was that field-dependent learners would be aided by the use of three-dimensional images. The results of the analysis for this hypothesis indicate that virtual environments in the context of Web-delivered instruction do not aid field-dependent learners in immediate recall.

Field-dependent individuals tend to perceive a visual field as rigid and without sub-parts (Witkin, Oltman, Raskin, & Karp, 1971), and the ability to disembed a figure from a background has been linked to one's ability to reverse perspective (Newbigging, 1954). It was hoped that by giving participants the ability to view an image from different perspectives and with some sense of depth that this figure-ground relationship might be broken, thereby helping field-dependent learners in their ability to recall the information. The lack of a significant difference in scores for field-dependent participants between the static-image and virtual-environment treatment groups indicates that the use of a virtual environment does not aid field-dependent learners' ability to recall information.

H_3: Field dependence interacts with the dimension of image type (static versus virtual environment).

Test scores for field-dependent participants in the virtual-environment treatment group were lower (Mean = 10.143, Standard Deviation = 4.589, Standard Error = 1.226) than for field-dependent participants in the static-image treatment group (Mean = 10.667, Standard Deviation = 3.848, Standard Error = .994) on the terminology test. Test scores for field-independent participants in the static-image treatment group were lower (Mean = 10.947, Standard Deviation = 4.116, Standard Error = .944) than for field-independent participants in the virtual-environment treatment group (Mean = 13.964, Standard Deviation = 4.384, Standard Error = .829). Results of the factorial analysis for the terminology test indicate no significant interaction between treatment and field dependence: $F(1, 72) = 3.055$, $p > .05$.

On the identification test, scores for field-dependent participants in the virtual environment treatment group were lower (Mean = 11.357, Standard Deviation = 3.153, Standard Error = .843) than for field-dependent participants in the static-image treatment group (Mean = 11.600, Standard Deviation = 4.171, Standard Error = 1.077). Test scores for field-independent participants in the static-image treatment group were lower (Mean

= 11.474, Standard Deviation = 4.647, Standard Error = 1.066) than for field-independent participants in the virtual-environment treatment group (Mean = 14.607, Standard Deviation = 2.936, Standard Error = .555). As was the case in the terminology test, the results of the factorial analysis for the identification test indicate that no significant interaction exists between treatment and field dependence: $F(1, 72) = 3.646$, $p > .05$.

The results of the overall score turn out somewhat differently. Again, test scores for field-dependent participants in the virtual-environment treatment group were lower (Mean = 21.500, Standard Deviation = 6.779, Standard Error = 1.812) than for field-dependent participants in the static-image treatment group (Mean = 22.267, Standard Deviation = 6.798, Standard Error = 1.755). Also, as with the subtests, test scores for field-independent participants in the static-image treatment group were lower (Mean = 22.421, Standard Deviation = 7.960, Standard Error = 1.826) than for field-independent participants in the virtual environment treatment group (Mean = 28.571, Standard Deviation = 6.785, Standard Error = 1.282). For the overall score, the results of the factorial analysis (Appendix IV) indicate a significant interaction between treatment and field dependence, favoring field-independent participants receiving the three-dimensional treatment: $F(1, 72) = 4.193$, $p < .05$.

While the subtests (terminology and identification) reveal no interaction between field dependence and the image type used, the overall score does indicate a significant interaction between field dependence and image type, favoring field-independent participants in the virtual-environment treatment group. It is not surprising that field-independent participants performed better than field-dependent participants did across the board. Prior research (Dwyer & Moore, 1992, 1995, 1999; Hall, 2000; Worley, 1999) indicates that field-independent individuals perform better at visual tasks than do field-dependent individuals. The desirable outcome, that field-dependent participants would perform better on the test of recall if they were in the virtual-environment treatment group, was not borne out by the research.

The results indicate that while the virtual-environment treatment did not aid the field-dependent participants in performing better on the test of recall, the virtual-environment treatment did assist the field-independent participants in obtaining a statistically significant higher score than had those in the static-image treatment group.

This suggests that virtual environments are helpful to some learners, while not adversely affecting others.

Conclusions

The vast majority of the research into virtual environments for instructional use is technology-driven, rather than taking into account the human component. Salzman, Dede, Loftin, and Chen (1999) cite the need for exploration of the interaction between learner characteristics and learning in virtual environments. There has been precious little study on how learner characteristics interact with the features of virtual environments to aid or inhibit learning. This study was designed to inquire as to whether providing field-dependent individuals with a virtual environment would aid them in scoring higher on a test of recall than had they been provided with two-dimensional images.

Salzman et al. (1999) list spatial ability, gender, domain experience, computer experience, motion-sickness history, and immersive tendency as some learner characteristics of interest in studies of virtual environments as learning tools. This study explored the notion that field dependence might be among these individual characteristics with an effect on learning in virtual environments. Virtual environments allow the learner to experience the information by allowing different perspectives and symbolic representations (Osberg, 1993); and, thus, it was hypothesized that virtual environments would in fact help field-dependent learners score higher on a test of recall. The results of this research do not support that hypothesis.

Winn and Snyder (1996) state that virtual environments can help in the formation of mental models. According to Winn and Snyder (1996), mental model theory is not limited to spatial knowledge but includes perception of the causal relationships between objects. As the instructional materials were designed to convey the parts, structure, and functions of the heart, providing a virtual environment of the heart seemed a sound strategy for improving field-dependent participants recall of the information.

Several of Winn and Jackson's (1999) propositions for learning in virtual environments were thought to lend support to the notion that virtual environments might help field-dependent learners:

- Students can learn in virtual environments.
- Virtual environments are most effective when changes in three-dimensional viewpoint contribute to learning.
- Virtual environments allow direct construction of knowledge, bypassing symbol systems.

Of the three propositions listed, the latter two seemed strong rationale for using virtual environments to aid field-dependent participants in scoring higher on a test of recall. With these affordances provided by virtual environments, why did the virtual-environment treatment help the field-independent participants while not helping the field-dependent participants as desired?

Some learning tasks in a virtual environment may be ideally suited for field-independent learners while others are not helpful to field-dependent individuals and should be avoided. It may be that the added depth and ability to rotate the image and view it from different perspectives, while intended to break the figure-ground relationship for field-dependent participants, only served to confuse and hinder them. Or field-dependent learners may have chosen to be more passive and not manipulate the images in the three-dimensional treatment.

As expected, field-independent learners performed better than field-dependent learners on the test of recall. But field-independent participants also performed significantly better on the test of recall when provided with the virtual environment than with the two-dimensional images. The fact that those field-independent participants in the virtual-environment treatment group scored significantly higher on the test of recall lends support to the contention of past research that virtual environments are a suitable tool for learning visual information.

The work of Salzman, et al. (1999) may offer an explanation for the significant interaction for field-independent participants. Salzman, et al. (1999) explain how learner characteristics may also affect the virtual environment's influence on learning. They state that the interaction between the virtual environment's features and the learner's characteristics has an effect on the interaction experience, or how the user interacts with the environment and the learning experience.

The Salzman, et al. (1999) model for how learning occurs in virtual environments describes how the features of virtual environments affect conceptual learning in virtual environments. According to the model, features of virtual environments are likely to influence the learning process and learning outcomes. Also, the ability for virtual environments to influence learning may depend on the concept being learned. Finally, individual learner characteristics may interact with features of virtual environments to influence learning, and it is likely that the affordances provided by virtual environments affect the interaction and learning experiences and, thus, learning.

The significant increase in test scores for field-independent participants who were in the virtual-environment treatment group adds to the support for the use of virtual environments for learning tasks involving visual information. The fact that the virtual environment was delivered over the Internet on equipment that would be available in the computer lab of many schools is encouraging for those interested in utilizing this technology at the classroom level.

It can be concluded from this study that virtual environments have no effect on the recall ability of field-dependent learners. Further research might focus on other individual differences, such as spatial ability, that may have an effect on field-dependent learners' strategies for working in a virtual environment.

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APPENDIX 1: HUMAN SUBJECTS BOARD APPROVAL

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE
AND STATE UNIVERSITY

Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice Provost for Research Compliance
CVM Phase II - Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
e-mail: moored@vt.edu

DATE February 5, 2002

MEMORANDUM

TO: Jeffrey Ogle Teaching and Learning 0313
John Burton Teaching and Learning 0313

FROM: David M. Moore

SUBJECT: IRB EXEMPTION APPROVAL – "The Effects of Three-Dimensional Images on Recall in Participants of Differing Levels of Field Dependence" – IRB #02-052

I have reviewed your request to the IRB for exemption for the above referenced project. I concur that the research falls within the exempt status. Approval is granted effective as of January 31, 2002.

cc:File
Department Reviewer: Jan Nespor

A Land-Grant University—The Commonwealth Is Our Campus
An Equal Opportunity / Affirmative Action Institution

APPENDIX 2: SUMMARY ANOVA TABLE FOR IDENTIFICATION TEST

	DF	Sum of Squares	Mean Square	F-Value	P-Value
FDI	1	43.090	43.090	3.121	.0816
Treatment	1	36.900	36.900	2.672	.1065
FDI * Treatment	1	50.342	50.342	3.646	.0602
Residual	72	994.230	13.809		

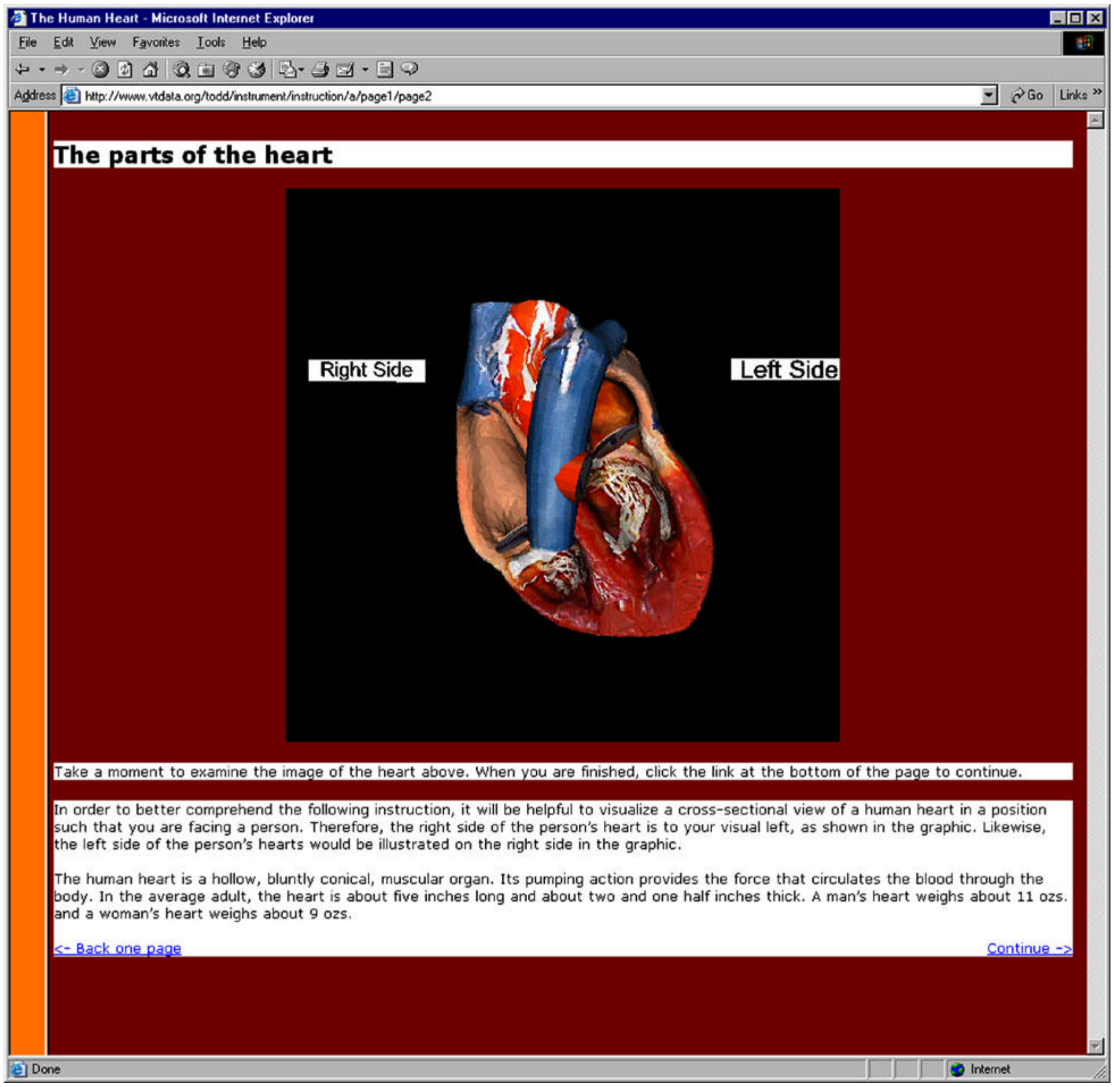
APPENDIX 3: SUMMARY ANOVA TABLE FOR TERMINOLOGY TEST

	DF	Sum of Squares	Mean Square	F-Value	P-Value
FDI	1	74.313	74.313	4.100	.0466
Treatment	1	27.449	27.449	1.514	.2225
FDI * Treatment	1	55.364	55.364	3.055	.0848
Residual	72	1304.959	18.124		

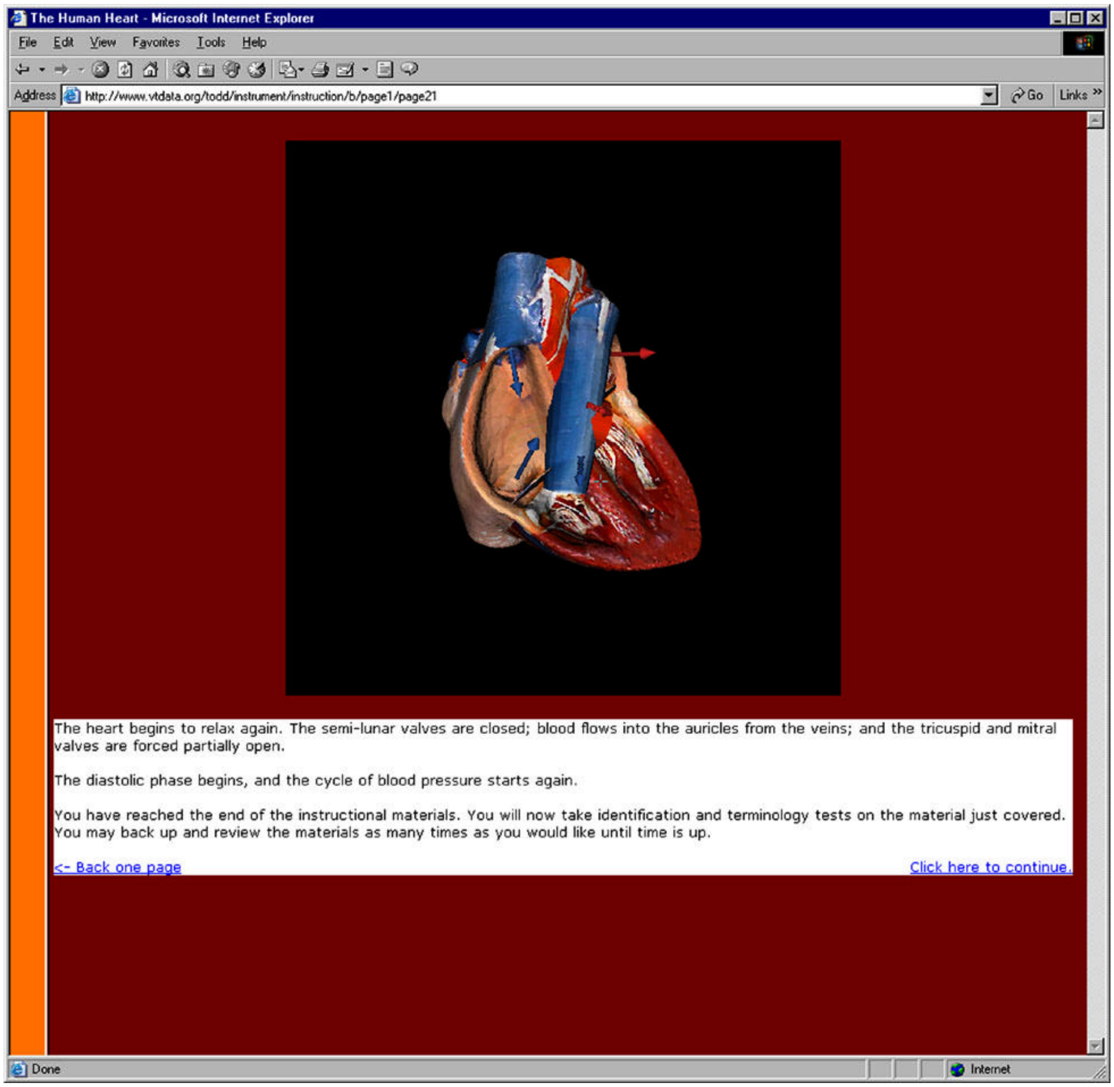
APPENDIX 4: SUMMARY ANOVA TABLE FOR OVERALL SCORE

	DF	Sum of Squares	Mean Square	F-Value	P-Value
FDI	1	230.578	230.578	4.576	.0358
Treatment	1	127.999	127.999	2.540	.1154
FDI * Treatment	1	211.293	211.293	4.193	.0442
Residual	72	3627.922	50.388		

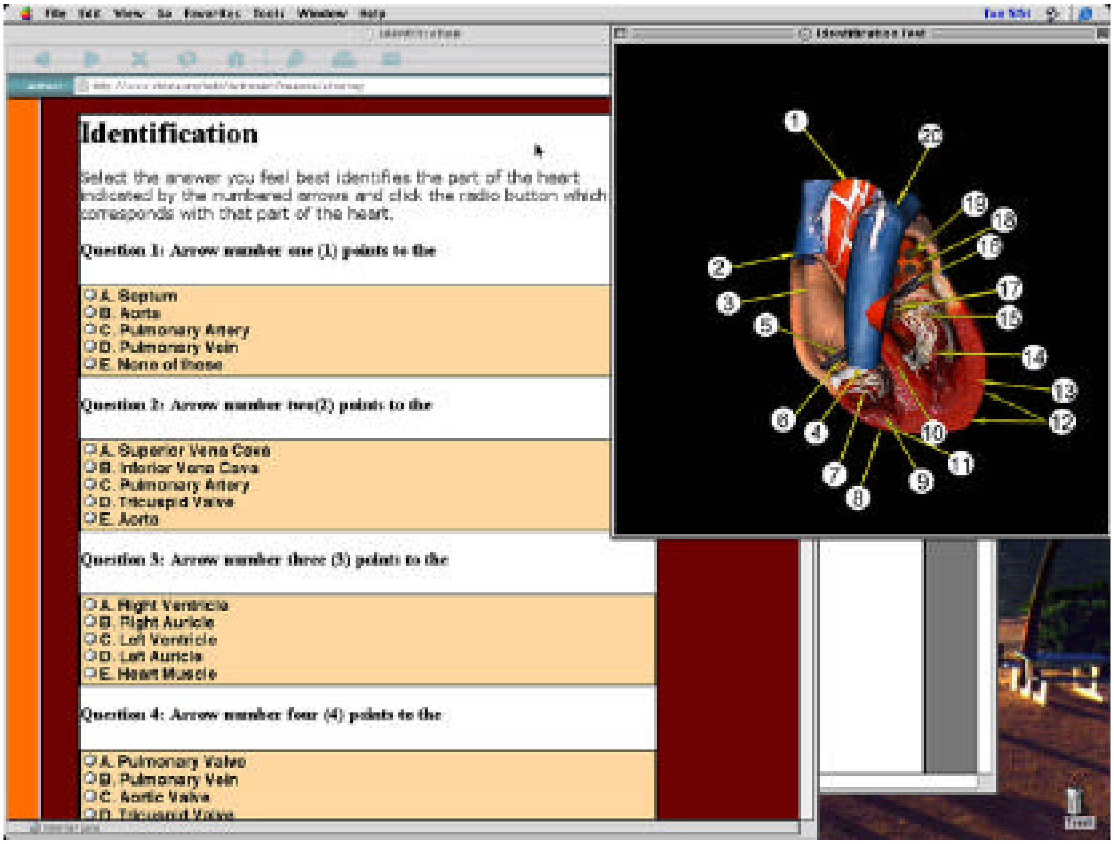
APPENDIX 5: EXAMPLE OF STATIC-IMAGE INSTRUCTION



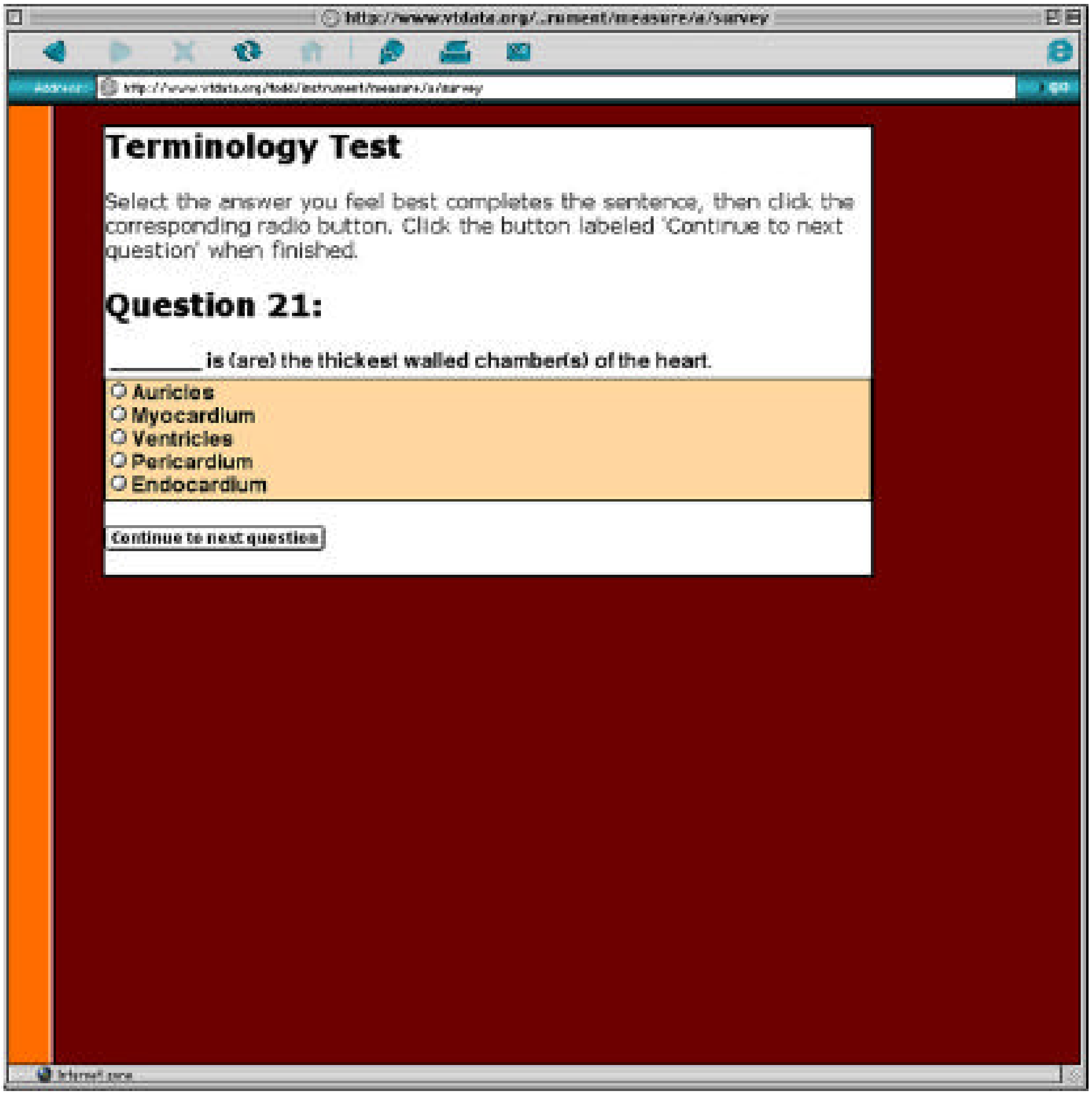
APPENDIX 6: EXAMPLE OF VIRTUAL ENVIRONMENT INSTRUCTION



APPENDIX 7: SCREENSHOT OF IDENTIFICATION TEST



APPENDIX 8: SCREENSHOT OF TERMINOLOGY TEST



VITA

TODD OGLE · 502 Lee Street · Blacksburg, Virginia 24060 · (540) 953-1577

Education

Ph.D, Instructional Technology, May 2002 – Virginia Polytechnic Institute and State University
M.A.Ed., Instructional Technology, May 1998 – Virginia Polytechnic Institute and State University
B.A., Communication Studies, May 1995 – Virginia Polytechnic Institute and State University

Professional Experience

Research Associate, Center for Assessment, Evaluation, and Educational Programming, Virginia Tech, July 2001 – Present.

Analyze data from state and local education organizations for program improvement and federal reporting requirements. Design survey instruments for paper and online data collection.

Internship, NASA Langley Research Center, June – July, 2001.

Interviewed actors and scientists on the NASA *Why Files?* television show; edited and prepared footage for Internet delivery.

Manager, Housecalls and Education Technology Lab, 1999 – 2001.

Managed staff and daily operations of Housecalls and Education Technology Lab, providing service to faculty, staff, and students in the College of Human Resources and Education.

Lab Staff/ Technical Support, Education Technology Lab, 1998 – 1999.

Provided computer technical support as part of Housecalls to faculty and staff in the College of Human Resources and Education, maintained and setup computers and audio/video equipment, provided hands-on assistance to users in Education Technology Lab.

Faculty Instructional Support, Department of Teaching and Learning, 1997 – 1998.

Managed and designed Web sites for several academic projects and courses, including: the Academy of Teaching Excellence (www.edtech.vt.edu/ate/), Principle's of Instructional Design (www.chre.vt.edu/courses/sumagsid/), the Rockbridge County Cohort Project (www.chre.vt.edu/projects/rockbridgeco/), and the Faculty Senate of Virginia (www.chre.vt.edu/projects/fsv/).

Communication Specialist, Waste Policy Institute, 1995 – 1997.

Site lead for the Decontamination and Decommissioning Homepage (www.wpi.org/doe/focus/dd/) and the Research for Communication and Public Involvement (www.wpi.org/rcpi/).

Managing editor of the newsletter Energy and Transportation Network News. Wrote and edited articles for the newsletter Initiatives in Environmental Investment.

Teaching

Introduction to Microcomputing in Foresty and Wildlife Resources
Instructor for semester-long undergraduate computing course at Virginia Tech.
Desktop Video Production
Team-taught semester-long graduate course with professor in Instructional Technology.
Writing and Editing in Public Relations
Prepared and delivered a lecture on Website development.

Tutored visiting film professor from Egypt on the Media 100 digital-video production system. Assisted in training Rockbridge County Cohort Project students in designing Web pages for course development.

Presentations

Ogle, T., & Kelso, J. (2001). Collaborative Virtual Environments for Education. Poster presented at the 2001 EDUCAUSE Annual Meeting. Indianapolis, IN.

Ogle, T., Schneider, S., Liu, H., Saenz, B., Macedo, P., & Farrell, I. (2001). Examining the Socio-Cognitive Relationship Between Context and Performance. Paper presented at the Annual Meeting of the Association for Educational Communications and Technology. Atlanta, GA.

Ogle, T. (2002). Does Presence in a Virtual Environment Aid Learning? Paper presented at the Annual Meeting of the Eastern Education Research Association. Sarasota, FL.

Ogle, T., & Byers, A. (2000). Evaluating Teacher's Perceptions of Technology Use in the K–8 Classroom. Paper presented at the Annual Meeting of the Eastern Education Research Association. Clearwater, FL. (ERIC Document Reproductions Service No. ED 443396)

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Publications

Ogle, T., Schneider, S., Liu, H., Saenz, B., Macedo, P., & Farrell, I. (2001). Examining the Socio-Cognitive Relationship Between Context and Performance. Paper presented at the Annual Meeting of the Association for Educational Communications and Technology. Atlanta, GA. To be published in the 2003 Selected Readings of the AECT.

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