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THE EFFECT OF AUGMENTED REALITY TREATMENT ON LEARNING, COGNITIVE LOAD, AND SPATIAL VISUALIZATION ABILITIES

DISSERTATION

A dissertation submitted in partial fulfillment of the

requirements for the degree of Doctor of Education in the

College of Education

at the University of Kentucky

By

Nedim Slijepcevic

Lexington, Kentucky

Director: Dr. Gary J. Anglin, Professor of Education

Lexington, Kentucky

2013

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ABSTRACT OF DISSERTATION

THE EFFECT OF AUGMENTED REALITY TREATMENT ON LEARNING, COGNITIVE LOAD, AND SPATIAL VISUALIZATION ABILITIES

This study investigated the effects of Augmented Reality (AR) on learning, cognitive load and spatial abilities. More specifically, it measured learning gains, perceived cognitive load, and the role spatial abilities play with students engaged in an astronomy lesson about lunar phases. Research participants were 182 students from a public university in southeastern United States, and were recruited from psychology research pool. Participants were randomly assigned to two groups: (a) Augmented Reality and Text Astronomy Treatment (ARTAT); and (b) Images and Text Astronomy Treatment (ITAT). Upon entering the experimental classroom, participants were given (a) Paper Folding Test to measure their spatial abilities; (b) the Lunar Phases Concept Inventory (LPCI) pre-test; (c) lesson on Lunar Phases; (d) NASA-TLX to measure participants' cognitive load; and (e) LPCI post-test. Statistical analysis found (a) no statistical difference for learning gains between the ARTAT and ITAT groups; (b) statistically significant difference for cognitive load; and (c) no significant difference for spatial abilities scores.

KEYWORDS: Cognitive Load, Augmented Reality, Spatial Visualization Abilities, Learning, Tactile

Nedim Slijepcevic Student's Signature

05/02/2013

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THE EFFECT OF AUGMENTED REALITY TREATMENT ON LEARNING, COGNITIVE LOAD, AND SPATIAL VISUALIZATION ABILITIES

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CHAPTER ONE: INTRODUCTION

Background

Introduction to Augmented Reality

Augmented reality (AR) is a relatively new concept that was first mentioned by Ivan Sutherland in 1965, who was developing the first head-mounted display (HMD) at that time (Billinghurst & Kato, 2002). Azuma (1997) defines AR as a technology that is closely related to Virtual Reality (VR) that supplements reality by superimposing virtual objects into it. Examples of AR in popular culture can be seen during broadcasted games of American football in the form of yellow "first down" lines and team logos that appear on the turf. In this scenario, AR enhances reality by augmenting virtual objects over the real world (Azuma, 1997).

Milgram, Takemura, Utsumi, and Kishino (1994) place AR in-between reality (real world) and virtuality (virtual environment) on Milgram's virtuality continuum. With its ability to superimpose virtual objects in real world, AR has the potential to be used in many fields - but especially in education for training purposes. An example of an educational application of AR would be real-time training for car mechanics. In this training scenario, trainees would wear a see-through HMD and they would be able to see a car engine with augmented step-by-step 2D or 3D instructions on how to replace a particular car part. With this type of training, a novice would be able to gain expertise in a relatively short period of time.

As an amalgam of real and virtual environment, AR has several unique properties: (a) it is excellent at representing spatial information (Shelton, 2003); (b) depending on the interface (fiducial marker based AR), AR can add a tactile sensory modality to learning

experience; and (c) AR can eliminate split attention effect by integrating multiple bits of visual information into one view. With these three properties, AR could potentially reduce the learner's working cognitive load that is created by the mental rotations required to process spatial information; and introducing tactile sensory modality would help spread the cognitive load.

The literature review of the AR field reveals numerous constructs that must be considered when discussing AR in educational context, and research in each of these constructs is limited. To examine this area further, this researcher will discuss research concerning AR from the perspective of working memory limitations and Cognitive Load Theory (CLT), and general AR research that pertains to learning, human spatial abilities, and tactile sensory input.

Memory Limitations and Cognitive Load Theory

According to Paas, Renkl, and Sweller (2003), Paas, Tuovinen, Tabbers, and Van Gerven (2003), and Van Merrienboer and Sweller (2005), human cognitive infrastructure, particularly working memory, is limited. This limitation can represent a barrier to more effective learning. One way to work around this barrier is to study the inner workings of the working memory and design instructional content around it. One theory that considers the limitations of working memory, with respect to the amount of information it can hold and the number of operations it can perform, is the CLT (Gerven et al., 2003; Sweller, 1994).

The CLT recognizes three types of cognitive load: extraneous, intrinsic, and germane (Sweller, Van Merrienboer, & Pass, 1998). Extraneous cognitive load is generated by the inadequate design of the instructional materials; intrinsic load is

generated by the difficulty of the learning materials; and germane load is generated by the amount of invested mental effort (Plass, Moreno, & Brünken, 2010). With properties such as superb depiction of spatial information and the ability to deliver tactile modality in a multimedia lesson, AR has the potential to enhance learning materials, reduce extraneous cognitive load, and promote intrinsic and germane cognitive loads.

Spatial Visualization Abilities

Spatial ability is a component of human spatial cognition that AR can utilize to promote deeper learning and conceptual understanding by learners with high and low spatial visualization abilities. Spatial abilities literature is broad and applies to numerous fields (human-computer interaction, geography, cognitive psychology, human factors, and so on). Review of the spatial abilities literature reveals the following hierarchical list: (a) spatial cognition; (b) spatial abilities with spatial orientation and spatial visualization; and (c) spatial knowledge.

Spatial cognition is a crucial component of human intelligence, and it is a component of Baddeley and Hitch's (1974) model of working memory. This model indicates that working memory consists of the phonological loop, episodic buffer, and the visual-spatial sketchpad. The focus of this study will be on the visual-spatial sketchpad. The visual-spatial sketchpad is responsible for remembering and processing information such as colors, shapes, location, movement, navigation through complex environments (buildings, outdoors), as well as kinesthetic information (movement).

Further down the hierarchy are spatial abilities with two main subcategories: (a) spatial orientation; and (b) spatial visualization (Strong & Smith, 2001). This study will focus only on spatial visualization. McGee (1979) described spatial visualization as the

ability to mentally rotate, manipulate, and twist two-dimensional (2D) and threedimensional (3D) stimulus objects. Eliot (2002) asserted that spatial intelligence is needed for almost every activity in everyday life, and Wickens and Hollands (2000) noted that spatial visualization abilities are important because they translate and mentally integrate 2D images into 3D objects.

Spatial knowledge categorized by its nature or type, and sources of spatial information are the last two spatial constructs that are briefly discussed in this study. The nature of spatial knowledge, as outlined by Mark (1993), Golledge and Stimson (as cited in MacEachren, 1991), and Wickens and Hollands (2000), consists of declarative knowledge or knowledge about objects (landmark knowledge in Wickens & Hollands, 2000), procedural or wayfinding knowledge (route knowledge in Wickens & Hollands, 2000) and configurational or "map like" (survey knowledge in Wickens & Hollands, 2000) spatial knowledge.

According to Shelton and Hedley (2004), AR interfaces most likely constitute some combination of procedural or configurational knowledge. AR may constitute procedural knowledge because its interface allows learners to "fly into" the 3D display and experience it as if they were standing or moving inside of a virtual world. AR may constitute configurational knowledge due to the interaction experienced by learners in which they hold a 3D model in their hands and view the geographical space (Shelton & Hedley, 2004).

Spatial knowledge that is categorized by sources of spatial information is divided into haptic space, pictorial space, and transperceptual space (Mark 1993). Haptic spaces are defined by tactile and kinesthetic sensory input; pictorial spaces are understood

through visual perception; and transperceptual spaces are learned mostly through interface during wayfinding (Mark, 1993). Out of these three spaces, Mark (1993) noted that sensory-motor and haptic perception are the most important early forms of spatial information that reach the mind.

AR uses all three sources of spatial information compared to most other technologies, which predominately operate in pictorial sources. Shelton and Hedley (2004) noted that this combination of strong pictorial and strong haptic spatial knowledge acquired from the interaction and manipulation offered by AR may result in more rapid and more accurate perception.

Tactile and Kinesthetic Sensory Input

Nojima, Sekiguchi, Inami, and Tachi (2002) asserted that the feeling of touch is an intuitive human sensation that often does not need interpretation. Jones, Minogue, Tretter, Negishi, and Taylor (2006) described touch as an active discovery sense and several researchers claimed that handling objects is an effective way for students to learn complex and abstract science concepts (Druyan, 1997; Glasson, 1989; Vesilind & Jones, 1996). Tactile and kinesthetic sensory inputs are key features of fiducial-based AR that is used in this study. This is because fiducial marker-based AR requires active user involvement, or physical manipulation of fiducial markers.

Like spatial visualization abilities, tactile and kinesthetic sensory information is also processed in visuo-spatial sketchpad (Baddeley, 2007). Logie (1995) classified visuo-spatial sketchpad into two components: (a) the visual cache, which stores information about color and form; and (b) the inner scribe, which processes spatial and movement information. Baddeley (2007) described the visuo-spatial sketchpad as a

"subsystem that has evolved to provide a way of integrating visuo-spatial information from multiple sources, visual, tactile and kinesthetic, as well as from both episodic and semantic long-term memory" (p. 101).

Since auditory and visual modalities have their own working memories (phonological loop and visuo-spatial sketchpad) with the ability to integrate information from multiple sources (Baddeley, 2007), Mousavi, Low, and Sweller (1995) claimed that using multiple modalities during instruction can help individuals learn better and reduce their cognitive load overall. Since AR can be described as a technology that utilizes multiple modalities, using tactile in addition to visual and/or auditory information during a lesson could potentially reduce a learner's cognitive load.

Overview of Augmented Reality Research in the Areas of CLT and Learning, Spatial Visualization Abilities, and Tactile and Kinesthetic Sensory Input

There is limited research on the impacts of AR on cognition, learning, perception, spatial visualization abilities, and the importance of tactile modality on learning. As Kerawalla, Luckin, Seljeflot, and Woolard (2006) noted that the use of AR in education is still in its infancy. The following three sections will briefly discuss the current state of research of AR in education.

Augmented reality interface comparisons, learning with augmented reality and learner's attitudes toward virtual reality. The literature reviewed in this section offers many insights into the effectiveness of AR during learning. The reduction and effects on cognitive load was a main topic of six studies (Tang, Owen, Biocca, & Mou, 2003; Haniff & Baber, 2003; Wang & Dunston, 2006; Klatzky, Wu, Shelton, & Stetten 2008; Chen, Wang, & Chiang, 2009; Kim & Dey, 2009). Research findings indicate that HMD-based AR reduced mental effort more than other interfaces, such as paper instruction, Computer Assisted Instruction (CAI) on a Liquid Crystal Display (LCD) monitor, and AR on LCD monitor (Tang, 2006; Haniff & Baber, 2003; Wang & Dunston, 2006). Klatzky et al. (2008) found that AR reduced the need for spatial visualizations, which translated into reduced cognitive load. Kim (2009) reported that AR display resulted in better driving performance and fewer issues with divided attention, which can be interpreted as reduced cognitive load, as well.

Literature that examined user satisfaction with the AR treatments reports mixed results. Juan, Beatrice, and Cano (2008) and Haniff and Baber (2003) reported that study participants liked and appreciated the AR interfaces that were presented to them during the experiment, but Leblanc et al. (2010) reported that participants appreciated the real physical treatment more than the equivalent AR interface.

Literature that focused on learning with AR showed that AR can more positively influence learning as opposed to traditional classroom materials (Vilkoniene, 2009). Yim and Seong (2010) found that the best AR lessons should have sequential steps with four to five informational chunks in each sequence for ideal learning and retention. Yim and Seong (2010), Tang et al. (2003), and Klatzky et al. (2008) reported increased learning and task accuracy during interactions with AR lessons. For collaborative learning, Dunleavy, Dede, and Mitchell (2009) reported that students viewed learning with AR as an authentic and novel way to learn science.

In the area of learner interest, Huang, Rauch, and Liaw (2010) reported that learner motivation increases in a 3D environment, while Dunleavy, Dede, and Mitchell (2009) and Yim and Seong (2010) reported that physical interaction with the AR lesson

made learning authentic, motivating, and efficient. In the area of collaborative learning, Dunleavy, Dede, and Mitchell (2009) and Huang, Rauch, and Liaw (2010) both found that collaboration with AR increased student interest, motivation, and problem solving.

Spatial visualization abilities. Spatial visualization abilities literature reviewed in this study focuses on the influence of 2D, 3D, instructional video, VR, animation, and problem solving on learners' visual spatial abilities. Research performed by Huk , Steinke, and Floto (2003), Kozhevnikov, Motes, and Hegarty (2007), Yang et al. (2003), and Cohen (2005) reported that the mode of representation had an impact on learners spatial visualization abilities, and generally, high spatial visualization ability learners preferred 3D and animation-based instructional materials over 2D images and graphs. On the contrary, Chen (2006) and Chen et al. (2009) reported that spatial abilities did not play a significant role in learning. However, Chen (2006) did find that guided AR instruction leads to better learning. Similar finding was reported by Yang et al. (2003) who found that instructor-led animations gave better learning results than static diagrams. From the CLT research, Moreno and Mayer (2005) and Rieber (2005) reported similar findings and they noted that guidance through each learning activity is required.

Shelton and Hedley (2002), Shelton (2003), and Hedley (2003) explored how AR influences the human understanding of spatial phenomena. Shelton and Hedley (2002) found that AR reduced misinterpretations during learning and improved student conceptual and factual understanding. Shelton (2003) reported that AR holds the following unique advantages for teaching and learning: (1) the ability to effectively communicate with reference to dynamic 3D objects; (2) the ability to regard virtual objects as both real and fake; and (3) that the "virtualness" of the objects affected how

students experienced the content and therefore changed the way they learned it. And lastly, Hedley (2003) found that AR interfaces provide advantages over desktop interfaces (for example, 3D on a PC) in a range of perceptual and task-based activities for users such as: task performance, task speed, completeness, and level of detail. From the cognitive load theory perspective, Hedley (2003) suggests that through multisensory interaction, AR interfaces may spread cognitive load for users, thereby reducing cognitive inertia.

Tactile and kinesthetic sensory input. Tactile and kinesthetic sensory input research studies are categorized into studies that focus on influence of tactile sensory modality on learning with AR, haptics, physical hands-on learning, and user perceptions and interactions with the tactile AR interfaces.

Research by Fjeld, Schar, Signorello, and Krueger (2002) compared AR lessons with traditional instructional methods, such as cardboard and physical models in a spatial laser-positioning problem, and concluded that AR treatment offered the same cognitive support as physical models. Hornecker and Dunser (2009) explored children's perception and interaction with AR 3D models and found that children who worked collaboratively took less time to complete the task and showed more signs of enjoyment. Perception of AR tangibility was researched by Shelton (2003), who found that AR often requires physical (tactile) interaction among participants for increased knowledge acquisition. In addition, Shelton (2003) found that visuo-motor activity offered by an AR interface led to expert knowledge of seasonal variation of light and temperature. This finding ties to the previously mentioned research by Peruch, Vercher, and Gauthier (1995), Yim and Seong

(2010), and Dunleavy, Dede, and Mitchell (2009), who found that more learning took place when participants physically engaged with the learning materials during the lesson.

In the area of haptics research, Minogue et al. (2006) and Jones et al. (2006) found significant differences in student learning when haptics were used during instruction. A study by Persson et al. (2007) found no obvious advantage from adding force feedback during pre-test and post-test analysis, but researchers did report that haptics successfully conveyed the key constructs during a biomolecular lesson

In the area of physical hands-on research, the Triona and Klahr (2003) and Klahr, Triona, and Williams (2007) studies compared physical learning materials with their software equivalents on a PC and found no significant differences in student learning.

Purpose of the Study and Research Questions

Clearly, research of educational applications of AR can be divided into three major areas: (a) effects of AR on working memory and consequently on learning; (b) effects of AR on spatial visualization abilities; and (c) implications of tactile sensory input on learning process. Each area is a crucial component of research that needs to be conducted on the effectiveness of AR as an instructional technology in education. Due to the difficulty of measuring the effects tactile sensory input has on learning, this study focused only on the effects of AR on learning, cognitive load, and spatial abilities. Therefore, the primary purpose of this study is (a) to examine how AR performs as a learning tool when compared to other instructional treatments, such as printed text with images instruction; (b) to determine if AR can decrease learner cognitive load; and (c) to determine if AR can supplement spatial visualization abilities of learners with low spatial abilities during learning. Examining how AR affects cognitive load is in line with research performed by Tang et al. (2003), who compared the effectiveness of AR as an instructional medium to three other instructional methods (printed media; CAI on LCD monitor, computer assisted instruction on a see-through HMD; and spatially registered AR by way of a seethrough HMD) in a computer-assisted assembly task from the cognitive load perspective. Improperly designed instructional materials can increase cognitive load and diminish learning (Van Merriënboer et al., 2002; Tabbers, Martens, & Merriënboer, 2004; Chandler & Sweller, 1991). Early research of AR indicated that when used in certain conditions, AR can potentially reduce cognitive load, but this research must to be expanded to include new topics, such as molecular interactions, solar system configurations and geographical land formations (Shelton, 2003). Additionally, integration of AR into the classroom or instructional settings either from a pedagogical or technological aspect should be examined (Chen et al., 2009).

Researching how AR can supplement spatial visualization abilities during learning is in line with research conducted by Shelton (2003), who examined how learners change the way they come to understand topics that involve dynamic spatial relationships while interacting with virtual objects (AR). This is an especially fertile area for research, as few studies that directly examine the impacts of AR on learners with low spatial visualization abilities exist. Since spatial visualization abilities vary among learners, it would be beneficial to determine if AR can help the individuals with low spatial visualization abilities with learning of spatial content (geography, astronomy, biology, and so on).

To examine the effects of (a) AR on working memory and learning; (b) on spatial visualization abilities; and (c) implications of tactile sensory input on learning process, this study used quantitative research methods. Data was collected with the following instruments: (a) Paper Folding Test for assessment of spatial visualization abilities (Paper Folding Test), which was developed by Ekstrom et al. (1976); (b) Lunar Phases Concept Inventory astronomy pre-test and post-test (LPCI) developed by (Lindell, 2001); and (c) NASA-TLX: Task Load Index (NASA TLX), which is an instrument for subjective measurement of cognitive load. The research questions that guided the inquiry were as follows:

- Is there any difference in learning gains for learners exposed to AR instructional treatment (AR and text lesson) compared to more traditional instructional treatment, such as text with images lesson?
- 2. Can AR lesson significantly reduce the cognitive load of learners when compared to more traditional instructional treatment, such as text with images lessons?
- 3. Can AR aid learners with low spatial visualization abilities and help them perform as well as learners with high spatial visualization abilities?

Definition of the Terms

This section defines the terms used throughout this research study.

Affordances

Norman (1988) describes *affordance* as perceived and actual properties of an object, especially fundamental properties that determine just how the thing could possibly be used. Norman (1988) gives several examples of affordances: a chair affords support and therefore affords sitting, but it can also be carried.

Augmented Reality

Azuma (1997) defined *augmented reality* (AR) as a variation of Virtual Reality (VR), and technology that supplements reality by superimposing virtual objects into it. An example of AR in culture can be seen during the broadcasted games of American football games in the form of yellow "first down" lines. These yellow "first down" lines depict the line that the offensive team must cross in order to receive a first down or a gain of 10 yards or more which would allow them to attempt another series of "first downs". In this case, AR enhances reality by mixing real views with virtual objects (Azuma, 1997).

Cognitive Load / Mental Workload

Cognitive load may be viewed as the level of "mental energy," required to process a given amount of information (Cooper, 1990). This concept is used throughout this study to describe the amount of mental processing required to process a particular learning task.

Fiducial Marker

A *fiducial marker* consists of patterns that are mounted in the environment (for example, printed on a paper) and automatically detected by a digital camera with accompanying detection mechanism (Fiala, 2005). This detection mechanism is usually software that monitors the incoming video stream from the camera and actively searches for the fiducial marker pattern within the stream. After the pattern is detected, a previously defined event is triggered. In an AR system, this event can be an augmentation of 2D, 3D, animation, or audio signal over the fiducial marker.

Haptic

Haptic means relating to or based on the sense of touch (Haptic, 2012). In this study, the term haptic refers to a technology that offers force feedback or the feeling of touch when interacting with virtual environments. Several research studies that examine the effects of force feedback or haptic technologies have been summarized in Chapter two of this study.

Head Mounted Display (HMD)

A Head Mounted Display (HMD) is a type of headgear, which is often used for training and in virtual environments. An HMD is operated by superimposing a visual information display (3D stereoscopic image) over a viewer's field of view (Liu et al., 2010).

Kinesthetic

The term *kinesthetic* in this study is used along with the term *tactile* to describe the sense of touch that is generated while interfacing various AR systems. McCloskey (1978) described *kinesthetic* sensation as:

Perceived sensations about the static position or velocity of movement (whether imposed or voluntarily generated) of those parts of the body moved by skeletal muscles and perceived sensations about the forces generated during muscular contractions even when such contractions are isometric (p. 763).

Liquid Crystal Display (LCD)

An *LCD* is an electronic display that consists of segments of a liquid crystal whose reflectivity varies according to the voltage applied to them (Liquid Crystal

Display, 2012). This type of electronic display has replaced cathode ray tube (CRT) displays as the most common way to display information electronically.

Spatial Cognition

Spatial cognition is fundamental to human life itself and it is an important component of Baddeley's and Hitch's (1974) model of working memory. Spatial cognition falls under the visuo-spatial sketchpad that is responsible for remembering and processing information, such as colors, shapes, location, movement, navigation through complex environments (buildings, outdoors), as well as the kinesthetic information (movement).

Spatial Visualization Ability

Spatial visualization ability is the ability to mentally rotate, manipulate, and twist 2D and 3D stimulus objects (McGee, 1979). Wickens and Hollands (2000) also pointed out that spatial visualization abilities are important as they translate 2D images into 3D objects and mentally integrate them.

Spatial Knowledge

Spatial knowledge is a spatial construct that resides independently outside of the human spatial cognition infrastructure and spatial abilities. Examples of spatial knowledge include everyday physical objects, such as buildings, paths, trees, etc. According to Shelton and Hedley (2002), humans acquire knowledge about spatial phenomena by viewing 3D objects (landscapes).

Tactile

Tactile refers to perception that is perceptible by touch (Tactile, 2012). Tactile modality is one of the unique properties of AR and its influence on learning will be further explored in this study.

Virtual Reality (VR)

Virtual reality (VR) is an artificial environment that is experienced through sensory stimuli such as visual or auditory stimuli, which is provided by a computer and in which one's actions partially determine what happens in the environment (Virtual Reality, 2012). VR is not the focus of this study, but it shares similar properties with AR, such as presence, spatial properties, and the ability to present tactile modality through the use of haptic devices.

CHAPTER TWO: REVIEW OF LITERATURE

Introduction to Augmented Reality

Augmented reality (AR) is a relatively new technological concept. It was first mentioned in 1965 when Ivan Sutherland developed technology that made it possible to overlay virtual images on the real world (Billinghurst & Kato, 2002). Azuma (1997) defined AR as a variation of Virtual Reality (VR), and a technology that supplements reality by superimposing or superimposing virtual objects into it. An example of AR in daily life would be use of a mobile device that enables its user to see the nearest point of interest, by utilizing live camera view. When pointed at certain direction, mobile device would display relevant information above point of interest, such as name of the object, distance, and other type of pertinent information. In this case, AR enhances reality by mixing real views with virtual objects (Azuma, 1997).

Figure 2.1 Milgram's Virtuality Continuum



Milgram et al. (1994) placed AR in the realm of mixed reality, the middle ground between reality and virtuality. As depicted on Figure 2.1, AR falls very close to the real

world on the Milgram's virtuality continuum. With this unique property, various industries and academic fields are trying to find the best fit for AR among familiar modalities, such as images, VR, and instructional video. In addition, certain implementations of AR allow the addition of tactile sensory input to multimedia learning and it is excellent at representing spatial information.

As an amalgam of the virtual and real environment, AR has several unique properties: it is excellent at representing spatial information and, with some interfaces such as fiducial-based AR systems, AR allows the learner to add tactile sensation to their learning experience. These two properties combined can potentially offload the learner's working memory load and introduce another sensory input to the learning process. Due to its unique properties, such as superb representation of spatial information and the possibility of adding a tactile modality to AR content, AR should be examined as a viable instructional technology from an educational and learning perspective.

There are many of constructs to consider when discussing AR in the context of instruction and limited research has been conducted in these areas. According to Kerawalla et al. (2006), the use of AR in education is still in its infancy. In order to examine this area further, AR research will be discussed from the perspective of working memory limitations and Cognitive Load Theory (CLT), and general AR research that pertains to learning, human spatial abilities, and tactile sensory input.

Two discussions of the literature that pertain to AR were identified: the first by Yu et al. (2010) and the second by Chen et al. (2009) Van Krevelen and Poelman (2010). Both discussions focus on the general overview of the AR field and act as a starting point for anyone interested in AR. Education and learning are briefly covered in both literature

discussions. Literature discussion by Yu et al. (2010) reviews the following areas of AR: tracking systems, medical applications, mobile applications, visualizations and AR, industrial applications, "edutainment", and hardware requirements for AR systems.

A literature discussion by Van Krevelen and Poelman (2010) went into more technical details and explains various components of AR systems such as displays, tracking, user interface and applications of AR. AR displays are one of the most important components of AR systems. According to Van Krevelen and Poelman (2010), there are three ways to visually present AR: video see-through, optical see-through, and projective displays. Video see-through interfaces are the most common and inexpensive AR interface and they are created by digitally altering a live video feed captured by the camera and augmenting visual objects within it. Optical see-through displays leave the real-world resolution intact while they augment the virtual objects over it. Projective displays are the last kind of visual displays and they do not require eyewear and they can cover large surfaces for a wide field of view.

AR displays can also be classified into three categories based on their position between the viewer and the real environment: head-worn, hand-held, and spatial (Van Krevelen and Poelman, 2010). Head-worn AR display devices include video and optical see-through displays (HMD), virtual retina displays (VRD), and head-mounted projective displays (HMPD). Hand-held AR displays include hand-held video and optical seethrough displays, as well as hand-held projectors. These types of devices offer the most cost-effective way to introduce AR commercially. Spatial displays are the last category of visual AR displays and they are often placed statically within the environment and can

include screen-based video see-through, spatial optical see-through, and projective displays. These interfaces are usually LCD computer monitors and televisions.

Tracking systems in AR are essential because AR systems need to know the position of the user relative to their environment to create an accurate 3D rendering view. Tracking systems can be sensor-based, vision-based, or a hybrid. Sensor-based systems can be mechanical, ultrasonic, magnetic, global positioning system (GPS) based, radio-based, or inertial. Vision-based trackers include a fiducial marker tracker, which relies on image recognition to track the position of the object that is to be augmented. This is the type of marker that will be used in this research study. A fiducial marker is usually a printed pattern (Figure 2.2) that can be physically manipulated by the user and it is used as a point of reference for the vision-based trackers.

Figure 2.2 An example of printed fiducial marker



Vision-based trackers track the marker on the X, Y, and Z axis of the Cartesian coordinate system and augment virtual objects over the fiducial marker. Van Krevelen and Poelman (2010) noted that there is a growing body of research on "markerless AR" for tracking physical positions in real-world environments. Hybrid tracking systems use the combination of visual-based and sensor-based tracking.

User interfaces in AR are numerous and include, but are not limited to: tangible user interface (TUI), 3D pointing, haptic user interface and gesture recognition, visual user interface and gesture recognition, gaze tracking, aural user interface and speech recognition, hybrid user interface, and context awareness.

There are countless applications of AR, but Van Krevelen and Poelman (2010) categorized them as follows: personal information systems that focus on wearable computing devices, industrial and military applications, medical applications, entertainment, office applications, and education. Each of these areas has many interesting examples of AR applications, which make this field exciting and ripe for research.

In summary, Yu et al. (2010) and Van Krevelen and Poelman (2010) agree that the current AR systems are limited, but both predict a bright future for AR. Both literature discussions agree that hardware is the biggest limitation of AR, as image processing for AR often means processing vast amounts of information. For example, in markerless AR, each frame of a live 29.97-frames-per-second video stream must be processed for pattern recognition. This requires powerful workstations and the portability of such systems is often reduced to the wired connection from the processing computer to the display device, such as HMD. Both reviews noted that portability and outdoor use need improvement, as most AR systems are too cumbersome to be used in an outdoor environment or carried by a user. Powering such systems creates another barrier, as these are processor-intensive computers that require a lot of power. Both reviews also agreed that tracker accuracy in current and future AR systems should be improved. Yu et al. (2010) asserted that occlusion detection, as well as analysis of various tracking methods,

should be further researched, which would allow researchers to effectively capitalize on the knowledge of video frames analysis or integration of vision-based tracking with other types of sensors in a novel way. Another venue for further research is the area of intelligent recognition systems, which will be able to acquire references or extract patterns from the real world in real time, and then augment them with real-time information.

Review of Literature

In the context of this literature review, three areas pertinent to the study of AR in education will be reviewed. In particular, literature that examines (a) AR interface comparisons, learning with AR and learner's attitudes toward virtual reality; (b) spatial visualization abilities; and (c) tactile and kinesthetic sensory input will be reviewed. Prior to these discussions, working memory limitations and Cognitive Load Theory will be briefly discussed to prime the reader on some of the concepts that will be discussed in subsequent chapters.

Memory Limitations and Cognitive Load Theory

Human cognitive infrastructure, particularly working memory, is limited (Paas, Renkl & Sweller, 2003; Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Van Merrienboer & Sweller, 2005). Several researchers have attempted to explain the limits of human cognition. For example, Baddeley and Hitch (1974) developed a model of working memory in an attempt to describe a more accurate model of short-term memory. Cowan (1998) developed an integrated framework of attention and memory. Additionally, Miller (1956) described the capacity limit of working memory. However, theories that focus

only on the limitations of the cognitive infrastructure are sufficient for explaining how learning takes place.

One theory that successfully explains the relationship between learning and human cognitive architecture is Cognitive Load Theory (CLT) (Sweller, 1994). Plass, Moreno, and Brünken (2010) asserted that the objective of CLT is to allow researchers to predict learning outcomes by taking into consideration the capabilities and limitations of human cognitive architecture. It has been designed to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance (Sweller, Van Merrienboer, & Paas, 1998). In general, CLT recognizes three types of cognitive load: extraneous, intrinsic, and germane (Sweller, Van Merrienboer, & Paas, 1998). Extraneous cognitive load is generated by the inadequate design of instructional materials; intrinsic cognitive load is generated by the difficulty of the learning materials; and germane cognitive load is generated by the amount of invested mental effort (Plass, Moreno, and Brünken, 2010). With its unique properties, such as superb depiction of spatial information and the ability to deliver tactile modality to a multimedia lesson, AR has the potential to enhance learning materials, reduce extraneous cognitive load, and promote intrinsic and germane cognitive loads.

Memory limitations during learning and CLT are the two concepts that are used to evaluate the impacts of AR on human cognition, and are often referred to in this literature review.

Augmented Reality Interface Comparison, Learning with Augmented Reality, and Learner's Attitudes toward Virtual Reality

One of the reasons it took nearly 40 years for AR to become viable and widespread technology is because technological demands for AR are much higher than for the virtual environments (Van Krevelen & Poelman, 2010). AR systems require several components for them to be considered AR system: spatial displays, position trackers, and user interfaces. Spatial displays such as head-mounted displays (HMD), seethrough HMDs, and monitors are required to combine the real and virtual worlds (Van Krevelen & Poelman, 2010; Bimber & Raskar, 2005). AR systems also require tracking sensors that can sense the environment and track the viewer's (relative) movement for correct registration of the virtual with the real (Van Krevelen & Poelman, 2010). Lastly, the user interface in AR is what makes AR so attractive for use in a wide variety of industries for training and learning, and this interface usually allows haptic manipulation of virtual objects (mostly 2D and 3D images, animation, sound, etc.). User interface in AR includes TUI, haptic interfaces, gesture recognition, gaze tracking, aural user interface, and hybrid systems. Almost all of these technologies began to flourish over the past two decades, but even today, most of them are not perfected. Spatial displays are often bulky and require a wired connection to an AR processing workstation or a mobile device; trackers often rely on environment analysis, which is processor-intensive to augment virtual objects in the real world; and user interfaces are still somewhat rudimentary or unavailable commercially to end users.

Over the past 10 years, most of the technologies associated with AR have become available commercially, which in turn made them available to a broader spectrum of

researchers, and resulted in an increase of AR literature. El Sayed, Zayed, and Sharawy (2011) pointed out that AR made good steps towards becoming a mainstream technology. Gartner's (2011) Hype Cycle Special Report, which provides strategists and planners with an assessment of the maturity, business benefit, and future direction of over 1,900 technologies, concluded that there have been great advances in the areas of human interface and computer analytics, which will directly contribute to future development of AR systems. However, much of the literature on AR applications in education is limited to argumentative or exploratory papers. What the field of AR applications in education is lacking are empirical research studies.

Review of literature related to augmented reality interface comparison. As a promising technology with the ability to offer tactile interface, AR in literature has been often compared to other already-established physical and digital interfaces and display technologies. For example, Haniff and Baber (2003) compared HMD-based AR with printed, textual instructions, while Tang et al. (2003) compared paper-based instructions with computer-assisted instruction (CAI) and LCD monitors. Juan, Beatrice, and Cano (2008), Wang and Dunston (2006), and Chen, Wang, and Chiang (2009) compared two types of AR interfaces: computer LCD monitors and HMDs. Vilkoniene (2009) compared LCD monitor-based instruction with classroom lecture and CAI. Finally, in medical training, Leblanc et al. (2010) compared human cadaver with AR-based training simulator and Klatzky et al. (2008) compared the ultrasound visualization technique with "Sonic Flashlight" which is also an AR-based interface. In addition to interface comparison, the following three studies that pertain to affordances, scaffolding, and learning-by-doing are identified and described.

Haniff and Baber's (2003) study (n=10) evaluated the appropriateness and performance of the AR system for a given task. To do this, the researchers compared a Water Pump Augmented Reality Tool (WART), which is a pump assembly system, to a paper version of the same assembly system. Three comparison dimensions were used to assess this appropriateness: analysis of a verbal protocol, since the participants were required to verbalize their experiences during the task; performance time; and a follow up questionnaire which inquired about student feelings towards AR instruction (the questionnaire was not solicited for paper treatment).

Statistical analysis concluded that paper-based WART instructions led to faster performance than the AR system. However, analysis of the verbal protocol indicated that the participants who used the paper version of WART uttered more words during the treatment. Haniff and Baber (2003) noted that the paper diagrams may have required the participant to translate the instructions mentally more than the representation associated with the real-world objects in the augmented reality system, thereby increasing the cognitive load. This was not the case with AR treatment, as AR treatment offered a more complete representation of the task, thereby eliminating the need for additional spatial visual representations. Study participants also reported that they appreciated the AR version of the treatment more that paper version, but also pointed out technical flaws associated with it. Some of technical issues reported were system lag caused by the computational intensity of the AR system; image disparity which is the offset of a camera view from the user's view of the real world; low image resolution; slow rendering; low maneuverability; and environmental conditions, such as improper lighting and electromagnetic disturbance. However, considering that Haniff and Baber's (2003) study
was performed in 2003 when the speeds of processors were still rather slow, one can assume that most of the technical issues, such as system lag, slow rendering, and low resolution, would be nonexistent with modern processors.

Similar to Haniff and Baber's (2003) study, Tang et al. (2003) tested the relative effectiveness of AR as an instructional medium in a computer-assisted assembly task, but from a cognitive load perspective. The study included 75 participants (university undergraduates) who were divided into four groups: printed media (n=19), CAI on LCD monitor display (n=18), CAI on a see-through HMD (n=19), and spatially registered AR via see-through HMD (n=19). Instructional materials were comprised of 56 steps in a single assembly task, and for each step subjects had to acquire a specific color and size part and orient it to the current subassembly according to the assembly instructions. Researchers wanted to do the following: (a) measure if AR can improve human performance during an assembly task when compared to other media (printed media, CAI, HMD); (b) determine a theoretical basis for cognitive support that AR provides; and (c) find any weaknesses in current AR interface design methodologies. To measure these three research objectives, researchers analyzed the participants' task performance (time for completion and accuracy of the task), and perceived mental workload using the NASA TLX cognitive load test.

Study results indicate that there was no significant advantage for AR treatment over CAI and HMD treatments in terms of time of completion. However, a significant statistical difference was observed between paper and AR treatment as participants completed the AR treatments on an average of several minutes before the paper instruction group. Tang et al. (2003) expected that the task performance would be

increased due to a reduction of head and eye movement between the workplace and the attached medium, which in turn would explain the differences between the paper and AR treatments. In the printed media group, participants had to look at the paper instructions and then back at the assembly task, thus dividing their attention and creating a split attention effect. Split attention effect is one of the categories of CLT and it occurs when learners are required to split their attention between at least two spatially or temporally separated sources of information (Ayers & Sweller, 2005; Sweller, Ayers, & Kalyuga, 2011). During the AR treatment, participants did not have to divide their attention, as the instructions were augmented over the physical blocks and they never had to look away to see where the next part would go. The AR group effectively reduced or eliminated the split attention effect and they completed the task quicker than the printed media group. In terms of the accuracy of the task, participants in the AR treatment were more accurate during the assembly task when compared to the other three treatments, as the researchers observed 82% error reduction for the AR assembly task.

The third hypothesis that assumed that the instructional material does have an effect on mental workload was supported as researchers found statistically significant differences in participants' cognitive loads between all four treatments. Using the NASA TLX to measure mental workload, participants in this study reported that the AR treatment was mentally less demanding. Tang et al. (2003) claimed that this finding is consistent with their hypothesis that AR reduces cognitive load by reducing the amount of mental manipulation of object location. An example of this could also be observed in the previously discussed elimination of the split attention effect between AR and paper treatments. To summarize, Tang et al. (2003) did find enough evidence to support the

notion that AR instructional systems can reduce mental workload and improve task performance.

Juan et al. (2008) compared traditional spatial display (LCD monitor) with an HMD device during the summer school of the Technical University of Valencia in Spain with 40 participants (ages 8-10). The AR system was designed to teach anatomical structures of the human body and it allowed tactile interaction with the users. Students were divided into two groups and administered two AR treatments. Upon completion of the task and subsequent statistical analysis, the researchers did not find any significant statistical differences between the two interfaces. Additionally, the order of the exposure to the treatment (HMD and LCD monitor) did not affect the test results. However, Juan et al. (2008) found that children considered both systems useful for learning about the human body.

Similar to Juan et al. (2008), Wang and Dunston (2006) also compared two AR interfaces (HMD and LCD monitor) and analyzed the feasibility of augmenting human vision with an AR interface during a construction task from the perspective of cognitive engineering. The researchers wanted to quantitatively assess the perceptual incompatibility caused by the improper selection of an AR interface (HMD and LCD monitor). The study participants were 16 engineering graduate students who attended both treatment sessions (HMD and monitor) and completed two possible sequences of two treatments. Treatments were comprised of orienting a fiducial marker to match a position of 3D virtual model of piping. Researchers hypothesized that (a) when compared to traditional monitor, using HMD would reduce the amount of time to complete a task; (b) when compared to an LCD monitor, using HMD should improve accuracy; and (c)

when compared to an LCD monitor, HMD should reduce the cognitive load. Similar to Tang et al. (2003), researchers measured task performance (time of completion and accuracy of the task) and perceived mental workload.

Study findings confirmed all three hypotheses. For the time of completion hypothesis, p value was <0.0001, which confirmed that the HMD treatment was superior to LCD monitor. Like the findings of Tang et al. (2003), this effect can be contributed to the reduction of the split attention effect, since the HMD treatment eliminated eye and head movements between the fiducial marker and the LCD monitor.

The second hypothesis (HMD improved accuracy over LCD monitor) was also confirmed as a statistically significant improvement in task precision. Wang and Dunston (2006) contributed this difference to the addition of mental rotations that learners must perform to accommodate for the mismatch of reference frames presented on the monitor and in their real world (fiducial marker). This effect can be explained from the spatial ability and cognitive load perspectives. This additional mental manipulation potentially burdened the working memory of learners with the low spatial abilities, and caused cognitive overload, which resulted in errors during precision placement. In addition, the mismatch for reference frames on the monitor and in real world may have caused the learners to look between the two interfaces, thus again causing the split attention effect. An interesting extension to this study would be if Wang and Dunston (2006) measured the spatial abilities of the study participants to compare if the learners with high spatial abilities were as cognitively overwhelmed during the CLT monitor treatment as their colleagues with low cognitive abilities.

The third hypothesis (HMD users should have experienced decrease in cognitive load) was also supported by the statistical analysis (p< 0.0001). Explanations for this result can also be drawn from individual spatial abilities and integration of the fiducial marker and 3D model with HMD, which practically eliminated the split attention effect. Wang and Dunston (2006) point out that learners who used the LCD monitor over an HMD had to engage in more perceptual activities, such as deciding, remembering, looking, and searching to complete the demanding orientation task. In summary, using HMD rather than an LCD monitor as an AR interface resulted in shorter task completion time, reduced orientation displacement, and reduced cognitive load.

The last study that compares HMD and LCD monitor type interfaces is by Chen et al. (2009), who explored how newer instructional technology, such as AR, can be used to facilitate student learning of chemistry concepts through analysis of effects of presence on learners' cognitive load and learning performance. Chen et al. (2009) described presence in virtual environments as a degree of attention shifted from the real world to virtual environments as if the users were situated in the artificial setting. The researchers hypothesized that the increased presence would translate into reduced cognitive load and increased learning performance. Fifty-eight study participants were divided into two groups (webcam and HMD group, n=29 each), and were given an AR-based interactive book (Protein Magic Book-PMB), which helped introduce basic concepts of protein structures.

Study results indicated the following: (a) students did not perform differently under different AR conditions (HMD and LCD monitor); (b) students with lower cognitive load did not perform differently from students with high cognitive load; (c)

spatial ability played no role during the learning process; and (d) the perception of presence did indeed affect student learning (Chen et al., 2009). One interesting finding that Chen et al., (2009) reported was that the students who interacted more with the learning materials, as well as the students with higher spatial abilities, had a higher presence, which in turn lowered their cognitive load. Physical interaction with the learning materials has been shown to positively increase participant performance (Peruch, Vercher, & Gauthier, 1995), and this area is covered in detail in the tactile and kinesthetic sensory input section of this review.

A study by Vilkoniene (2009) analyzed the influence of AR technologies on student knowledge about the human digestive system. This study encompassed 110 seventh grade students from a school in Lithuania. Vilkoniene (2009) divided the students into three groups: AR, computer program, and lecture group. They each delivered the same lesson about the human digestive system. Statistical analysis showed that the only statistically significant difference on the pre-test scores in all three groups was between the AR and lecture groups and the difference was in the knowledge of the organs of digestive system. Post-test analysis (Mann-Whitney test) yielded statistically significant differences (p<0.05 and p<0.01) between scores for AR and computer program groups. In summary, Vilkoniene (2009) found that the AR lesson, when used with traditional verbal and printed teaching materials, positively influenced student learning acquisition of human digestive system.

Leblanc et al. (2010) examined an alternate interface by comparing a human cadaver model with an AR simulator for straight laparoscopic colorectal skills acquisition. Study participants (n=35) were divided into an AR simulator group (n=28)

and a human cadaver group (n=7) and were compared according to their technical skills and event scores, as well as their satisfaction with the training model. Researchers assessed study participant performance based on generic and specific technical skills, and events using the Objective Structured Assessment Technical Skills forms completed independently by trainers and trainees. Researchers reported several findings: technical skills scores for trainers and trainees were better on the AR simulator than on the cadaver. Generic events score for the trainers was also considerably better using the simulator than using the cadaver, but an overall higher satisfaction was observed for the human cadaver over the AR simulator. This is understandable, as the real tissue (with its physical properties) offers unique tactile sensory information that could be difficult to achieve with any haptic device. Researchers concluded that AR simulator training could be integrated into the laparoscopic colorectal skills training by offering the AR training prior to cadaver training so that the benefits of both trainings are maintained.

Another study that investigate the influence of AR on medical training was performed by Klatzky et al. (2008), who examined the impacts of the AR visualization tool when compared to the conventional ultrasound procedure of guided needle insertion. This was another interface comparison study in which two interfaces were compared and cognitively assessed.

Klatzky et al. (2008) examined the conventional ultrasound system (CUS) first. CUS is often used during laparoscopic surgery and enables its users to perform medical procedures without direct sight of the affected issue through a small incision while viewing a remote screen. The remote screen is the screen that displays the real time image of the procedure in progress and surgeons need to gaze at it during the surgery.

The second interface ("Sonic Flashlight") is an AR-based system that augments the realtime image of the operation over the object that is being operated on, thus eliminating remote viewing. According to Klatzky et al. (2008), remote view presents problems because the surgeons are disconnected from the action itself. Similar to the Wang and Dunston (2006) study, remote viewing can cause displaced hand-eye coordination, as users must keep their attention focused on the remote display instead of the site of operation. Klatzky et al. (2008) asserted that additional cognitive processes are required in order to normalize the metric of the display, align multiple frames of reference, and form a representation of the target for planning and guiding the action. This is also in line with the causation of the split attention effect since surgeons must split their attention between the two sources of information: tactile input at the site of the operation and the visual input at the remote display monitor.

Three experiments were conducted in this study to examine the impacts of AR visualizations. The first experiment (n=12) examined learning through plane needle insertions, which were guided by two interfaces, CUS and Sonic Flashlight. The second experiment was similar to the first experiment, but the needle insertion points were differently positioned. The third experiment utilized in-plane needle insertions (in-plane refers to an ultrasound field of view) to further reduce the need for cognitive mediation to represent target location. In all three experiments, and especially in the third experiment with in-plane insertions, the Sonic Flashlight showed higher accuracy and lower variability in needle aiming than CUS did. Study participants did not have to cognitively mediate visual and spatial representations because the Sonic Flashlight eliminated the need to do so. AR treatment proved better than the CUS interface because it eliminated

the need to build spatial visualizations, thereby relieving the cognitive load (Klatzky et al., 2010). Results of this study were similar to the results in Wang et al. (2006), who also found that interfaces (HMD) that were spatially integrated with the task being performed, can reduce orientation displacement and reduce cognitive load.

Summary of augmented reality interface comparison studies. Research in this section indicates that when compared with other instructional materials, systems, or methodologies, AR tends to lower cognitive load (Haniff & Baber, 2003; Tang et al., 2003; Klatzky et al., 2008), reduces assembly errors and improves performance and accuracy (Tang et al., 2003; Wang & Dunston, 2006; Klatzky et al., 2008), and positively influences learning (Vilkoniene, 2009).

When comparing AR interfaces such as an LCD monitor and HMD, Wang and Dunston (2006) found that that the HMD interface reduces cognitive load over an LCD monitor, while Chen et al. (2009) and Juan et al. (2008) found no significant difference. In addition, Wang and Dunston (2006) found that the HMD interface reduces the time it takes to complete a task while Tang et al. (2003) found no significant difference in the time to complete a task between the four treatments.

User satisfaction varies and it depends on the AR system itself. Haniff and Baber (2003) found that participants preferred paper instruction over AR treatment. A reason for this may lie in the fact that AR technology in 2003 was "buggy" and unreliable when compared to paper instruction, which is always consistent and does not suffer from technological flaws like AR did. The study participants in Leblanc et al. (2010) also preferred non-AR interface instruction (cadaver), but in overall test scores, AR treatment

was superior to cadaver treatment. And finally, Juan et al. (2008) found that the study participants liked both implementations of the AR system (LCD monitor and HMD).

Review of literature related to learning with augmented reality. Klatzky's (2008) study was the last study that compared various AR interfaces with other types of interfaces and instructional technologies on the basis of learning, mental effort, collaboration, satisfaction, completion time, precision of task, affordances and presence. The following studies by Dunleavy, Dede, and Mitchell (2009); Yim and Seong (2010); Hsiao, Chen, and Huang (2010); Blake and Butcher-Green (2009); Kim and Dey (2009), and Huang, Rauch, and Liaw (2010) will investigate various applications of AR in the learning environment with focus on learning affordances, learning by doing, scaffolding, declining cognition, and facilitation of learning.

Dunleavy, Dede, and Mitchell (2009) explored affordances and limitations of immersive participatory AR simulations by studying how middle and high school students (n=80) and teachers describe teaching and learning with a mobile AR application. The subject of the AR lesson was an immersive, handheld-based (Dell Axim X51 handheld computer) AR lesson called "Alien Contact!". The lesson was designed to teach students math, language arts, and scientific literacy, and it was delivered in a narrative-driven, inquiry-based format (Dunleavy, Dede, & Mitchell, 2009). This experiment was not conducted in the classroom setting, but out in the open, where students moved around the school playground and used their handheld computers to display text, video, and audio files when they approached certain physical locations on the map. The lesson was designed for students to work collaboratively in teams. Data was

collected through observations, formal and informal interviews, as well as through website postings.

Results of this study were multidimensional. Dunleavy, Dede, and Mitchell (2009) reported that most students and teachers thought that the physical exploration of the school grounds was highly motivating, that it made the learning authentic, and when probed about the benefits of being outside, most students replied that it was novel for them to be learning mathematics in such a non-typical manner. This type of learning allowed for distributed knowledge, as all teams had different pieces of the puzzle and to complete the lesson, students had to collaborate among the teams. The approach to learning in this study was similar to constructivist learning and Vygotsky's (1978) social-cultural theory, which states that an essential feature of learning is the creation of the zone of proximal development. According to Vygotsky (1978), a variety of internal developmental processes awake through this zone of proximal development, and are only able to operate when learners interacting with their peers.

Some of the problems reported by the researchers included hardware and software issues, and in some instances increased cognitive overload with student learners, which was potentially created by the high element interactivity or complex lesson materials. Dunleavy, Dede, and Mitchell (2009) reported that students reported feeling frequently overwhelmed and confused with the amount of material and complexity of tasks they were asked to process during the simulation, thus causing them to give up. To prevent this in the future, perhaps a training session that outlines what and how students will be doing may be warranted.

Yim and Seong's (2010) double study measured the optimum amounts of information to be delivered during a training session without overloading learners' working memory (experiment 1). Additionally, Yim and Seong (2010) wanted to determine what types of information enhance the learning ability of novices and to suggest heuristic guidelines by which to make effective AR training instructions (experiment 2).

The first experiment included 42 graduate students who were assigned to seven groups (or seven modes), who was further divided into four groups that each assessed optimal chunking, and three groups that assessed the most suitable types of information to be presented in an AR learning environment. The chunking or segmenting principle is an important concept described by Mayer (2005), which states that people learn better when a multimedia lesson is presented in learner-paced segments, rather than as one continuous lesson. The lesson was AR-based (industrial water pump) and included 3D animations and narrations. A statistical analysis between all of the groups revealed that group 2, which utilized four or five chunks of information at any given time, achieved the highest score.

The second experiment was designed to determine the efficiency of heuristically suggested guidelines based on nine principles for reducing cognitive load from the Cognitive Theory of Multimedia Learning (CTML), as outlined in Mayer and Moreno (2003). Study participants were 15 graduate students, who were split into three groups with the following three AR treatments: an AR lesson based on sequential procedure; an AR lesson based on nine ways of reducing cognitive load as outlined by Mayer and Moreno (2003); and a heuristically-based AR lesson that used CTML as template for its

own design. The heuristically-based AR lesson adjusted the original Mayer and Moreno's (2003) nine ways to reduce cognitive load guidelines and the reason for this is because AR is a distinct technology that offers tactile modality in addition to visual modality. CTML was designed with auditory and visual multimedia content in mind and some of its principles do not apply to AR.

One of principles that was eliminated altogether from the heuristic guidelines is the individual differences principle because AR models are augmented over the real environment, so earners need not hold any mental representations of an object in memory (Mayer & Moreno, 2003). The second guideline that was not included in the heuristic guidelines was the pre-training principle because the number of training repetitions is controlled by the design of the experiment, not by the guidelines of the study. Yim and Seong (2010) added interaction as an additional load-reducing method because AR offers direct tactile interaction. In addition, animating and schematizing were added to the guidelines but Yim and Seong (2010) did not fully elaborate how these two effects reduced cognitive load. The results of the second experiment did not yield a statistical difference between the three treatments, but t-test did reveal slightly better performance of students who were in the suggested heuristic guidelines group over CTML group. Another finding was that learners displayed high interest when interacting with the AR system and this reflected on learning efficiency.

Hsiao et al. (2010) explored an unusual but culturally relevant application of AR in learning environments – learning with AR while exercising. Hsiao et al. (2010) asserted that concerns about adolescents have recently been raised in Taiwan since student exercise in educational environment has been limited due to scheduling

constraints. This study used 1,211 seventh grade students who were divided into five groups. The first three groups were exercise and AR-based and they included a games group, learning group, and an amalgam of a games and learning group. The fourth group was a keyboard/mouse-based computer assisted instruction (KMCAI) and the fifth group utilized traditional face-to-face classroom instruction. The main hypothesis of this study was that Ecosystems Augmented Reality Learning System (EARLS) could help students improve their achievement as well as the positive learning attitude change towards EARLS.

Study results indicate that students within EARLS learn just as well as the other groups, with the exception of the AR games group who scored lower (Hsiao et al., 2010). Similar to Dunleavy, Dede, and Mitchell (2009), this can be explained from a constructivist perspective. The students in all AR treatments were exposed to the same learning materials as the students in CAI and lecture treatment, but what they might have missed during the lesson due to potential less exposure to the learning materials, they made up with collaborative learning with their peers. Hsiao et al. (2010) concluded is that the concept of "Learning while exercising" provides a convenient and effective way to address health concerns while not diminishing the quality of learning achieved in the classroom, particularly in educational environments where student exercise has been limited by scheduling constraints.

A study by Blake and Butcher-Green (2009) explored scaffolding as an instructional approach to learning intensive tasks, such as completing a jigsaw puzzle. For this study, researchers designed an AR system that adapts to the skills of the individual trainee as it adaptively scaffolds and guides the learner toward task

completion. An experiment was conducted over a two-day period. During the first day, 46 women (ages 11-14) were trained on how to use the AR scaffolding system and were given preliminary tests to determine which subjects would be used for the main experiment. On the second day, 10 participants were chosen based on their performance during the first experiment and then they were divided into two groups: one group where adaptive scaffolding was used and where removal of learning aids was tailored in realtime to the trainee, and one group with a passive scaffolding system in which the learning aids were statically and systematically removed. Participants went through the training session and after it was complete, they were given a new puzzle without any scaffolding to assess for any differences in performance. Researchers then measured the student performance. Statistical analysis showed that the students who received adaptive scaffolding performed better than the group that received static scaffolding.

These results are similar to the guided discovery principle guidelines described by de Yong (2005), who said that guidance should be adapted to the actual behavior of learners, their prior knowledge, and learners' scientific discovery skills. For future work, Blake and Butcher-Green (2009) suggested that more research should be focused on the delivery of enhanced modes of training via next generation interfaces, such as AR, and that the effects of scaffolding in training environment should be investigated further.

Kim and Dey (2009) explored the issue of declining spatial cognition with aging automobile drivers with the use of a simulated AR windshield display. Declining spatial cognition is characterized by cell loss and widespread decreases in neural and metabolic efficiency (Reuter-Lorenz, Stanczak, & Miller, 1999) and one of the central findings in cognitive aging research is that the efficiency of working memory declines with age

(Pass, Van Gerven, & Tabbers, 2005). But Pass, Van Gerven, and Tabbers (2005) also noted that working memory limitations can be expanded by using more than one sensory modality, which is in line with CLT and CTML. To determine if AR can help aging drivers, Kim and Dey (2009) utilized 24 drivers, 12 of which were elderly drivers over the age of 65 (range/mean/SD: 66-85/74.25/5.48), and 12 were younger drivers (19-41/30.42/5.68). Researchers wanted to find out whether using an AR display (windshield navigational system) would result in better driving performance and fewer issues with divided attention, and whether elder drivers using the AR display would have better driving performance and fewer issues with divided attention compared to using the non-AR display.

Results confirmed both hypotheses, as the AR display did result in better driving performance and fewer issues with divided attention across most measures when compared to the non-AR display. AR display has been more effective in enhancing elder drivers' navigation performance and it has caused less divided attention than the non-AR display (Kim & Dey, 2009). Findings by Kim and Dey (2009) were similar to several studies that found that AR can improve task performance and reduce divided attention (Tang et al., 2003; Wang & Dunston, 2006; and Klatzky et al., 2010). In this case, AR instructions were helpful during task completions as the users did not have to divide their attention between the in-car navigational and driver's view through the windshield. One thing the researchers neglected to mention was the cognitive load and if the AR overlay caused extraneous mental load on the driver. It is possible that by eliminating the split attention effect by integrating additional information into the driver's view, researchers

caused additional load because drivers would have to pay attention to the information on the road as well as the information provided by the AR interface.

Summary of learning with augmented reality. This section focuses on the literature that investigated how learning takes place with AR. Some of the learning concepts are already covered in the previous section (AR Interface Comparison Studies), so there will be some overlap between the two sections.

Dunleavy, Dede, and Mitchell (2009) explored a constructivist approach to learning with outdoor AR on mobile devices and found that students perceived this type of learning as motivating and authentic. Dunleavy, Dede, and Mitchell (2009) also found that the students liked this novel approach to math instruction and that this type of collaborative environment transformed previously disengaged students into active learners. Hsiao et al. (2010) also explored active learning in their study by comparing classroom instruction with physical AR lessons and found them to be equally effective.

Yim and Seong (2010) experimented with the ideal amount of information to be delivered during one instructional sequence in AR lesson and found that number to be four to five informational chunks. Yim and Seong (2010) also experimented with the altered guidelines that apply to multimedia learning, as suggested by the CTML (Mayer & Moreno, 2003), and found that AR does not always adhere to its principles due to the addition of tactile modality and realistic 3D imagery. Researchers found that newly developed heuristic guidelines performed better than the lessons designed strictly according to the CTML rules. In addition, Yim and Seong (2010) found that learning increased when the users are actively interacting with the AR models.

In the area of adaptive scaffolding, Blake and Butcher-Green (2009) explored whether people learn better when adaptive scaffolding is used and found statistically significant differences between passive and active scaffolding groups.

And lastly, in the area of cognitive aging, Kim and Dey (2009) found that AR can improve task performance and reduce divided attention (Tang et al., 2003; Wang & Dunston, 2006; Klatzky et al., 2010).

Review of literature related to learner's attitudes toward virtual reality. The last reviewed study in this section is one by Huang, Rauch and Liaw (2010), who investigated learners' attitudes towards VR environments in two case studies. The Huang, Rauch, and Liaw (2010) study did not focus on AR, but on Web-based, 3D virtual environment. Since AR and VR both belong to the realm of mixed reality, this author believes that these two modalities have similar properties (immersion, collaborative learning, and presence) to be included in this literature review.

The first case study was conducted with a Web-based, 3D VR virtual body learning system, which was used to teach undergraduate medical students about the structure of the human body. Researchers hypothesized that with increased immersion and imagination provided by VR, motivation of learners would increase as well as the problem-solving capability of the environment. The study participants were 167 undergraduate students who completed a 16-item likert scale survey. The second case study was performed with a 3D human organ learning system that operated in two modes: single user self-learning mode and collaborative learning mode. Huang, Rauch, and Liaw (2010) hypothesized that this system would positively impact student collaborative

learning from three aspects: interaction, immersion, and imagination. Participants in this study were 76 medical students who took the 25-question likert scale test.

The results of the first study confirmed that learner motivation, as well as the problem solving capability of the environment, does indeed increase in a 3D VR environment. The results of the second study indicated that interaction, immersion, and imagination were all predictors the collaborative learning. The results of both experiments indicate that a virtual environment can be successfully used for collaboration and problem solving tasks while maintaining high levels of student motivation. Dunleavy, Dede, and Mitchell (2009) reported similar findings and suggested that physical interaction and collaboration made learning authentic and highly motivating. For future research, Huang, Rauch, and Liaw (2010) suggested that the effectiveness of 3D virtual learning are warranted due to the small number of empirical studies in this area. Additionally, Huang, Rauch, and Liaw (2010) suggested that the ability of VR to decrease cognitive load (extraneous cognitive load) and its impact on learners should be examined further.

Summary of augmented reality interface comparison, learning with augmented reality and learner's attitudes toward virtual reality. Reviewed literature offers many insights into the effectiveness of AR during learning. R\The reduction and effects of AR on cognitive load was subject or component of six studies (Tang et al., 2003; Haniff & Baber, 2003; Wang & Dunston, 2006; Klatzky et al., 2008); Chen, Wang, & Chiang (2009); Kim & Dey, 2009). In general, research findings indicated that HMDbased AR reduced mental effort more than other interfaces, such as text with images

(paper) instruction, CAI on an LCD monitor, and AR on an LCD monitor (Tang, 2006; Haniff & Baber, 2003; Wang & Dunston, 2006). Klatzky et al. (2008) found that AR reduced the need for spatial visualizations, thus reducing the cognitive load. Chen, Wang, and Chiang (2009) did not find any significant difference when comparing two AR interfaces (HMD and LCD monitor) in terms of presence, effects of presence on learning performance, and total cognitive load. Lastly, Kim and Dey (2009) reported that an AR display did result in better driving performance and fewer issues with divided attention, which can be interpreted into reduced cognitive load. The reason for this interpretation is the term "divided attention", which is common in human factors research is also synonymous to the split attention effect from CLT. Split attention effect is a major contributor to the extraneous cognitive load since learners must mentally integrate several sources of information at once (Sweller, Ayres, & Kalyuga, 2011). Only one study performed by Dunleavy, Dede, and Mitchell (2009) reported that AR may have increased the cognitive load in students because students were not prepared for the task given to them and were often confused about what they were supposed to do in order to complete the task.

User satisfaction is a dimension explored in studies by Juan, Beatrice, and Cano (2008), Haniff and Baber (2003) and Leblanc et al. (2010). Juan, Beatrice, and Cano (2008) and Haniff and Baber (2003) reported that study participants liked and appreciated AR interfaces that were presented to them during the experiment. However, Leblanc et al. (2010) reported that participants appreciated the real physical treatment (cadaver) more than the equivalent AR interface. AR is a burgeoning new technology with rapid

developments in the areas of tracking, displays, and user interface, so it is expected that AR technology will improve over time, and with it, user satisfaction will also improve.

Learning with AR is another big area of research with several subcategories. Vilkoniene (2009) found that when used in combination with traditional classroom materials (verbal instruction and printed text), AR positively influenced student learning. Yim and Seong (2010) found that an AR lesson should have sequential steps with four to five informational chunks in each sequence for ideal learning and retention. In addition, Yim and Seong's (2010) concluded that learning is increased when users actively interact with AR models. Tang et al. (2003) reduced errors in assembly tasks by 82%, and similar to Klatzky et al. (2008), they improved task accuracy. Dunleavy, Dede, and Mitchell (2009) found that students viewed interaction with the AR system (mobile outdoor system) as authentic learning and pointed out that many quiet students became active participants during the activities. Kim and Dey's (2009) analysis of elderly drivers during the driving experiment found significant improvements in driving performance and navigation of elderly drivers who used the AR treatment. Leblanc et al. (2010) found similar results with their Sonic Flashlight AR interface, as the Sonic Flashlight group performed significantly higher than the cadaver group. Blake and Butcher-Green (2009) explored whether people learn better when adaptive scaffolding is used and found statistically significant differences between passive and active scaffolding groups. In the area of collaborative learning, Dunleavy, Dede, and Mitchell (2009) and Huang, Rauch, and Liaw (2010) both found that collaboration with AR increased student interest, motivation, and problem solving.

Motivation and learner interest were two common topics that were extensively covered by Huang, Rauch, and Liaw (2010), Dunleavy, Dede, and Mitchell (2009), and Yim and Seong (2010). Huang, Rauch, and Liaw (2010) explored the use of 3D virtual environments and found that learner motivation as well as the problem solving capability of the environment does indeed increase in the 3D VR environment. Dunleavy, Dede, and Mitchell (2009) reported similar findings and suggested that physical interaction with the AR lesson made learning authentic and motivating. And lastly, Yim and Seong (2010) found that learning efficiency increased due to the learners' interest through interaction.

The last dimension that was frequently measured in reviewed studies was the time to complete the task. Wang and Dunston (2006) found that when compared to the traditional LCD monitor, HMD reduced the amount of time it took to complete a task. However, Haniff and Baber (2003) found that an AR task was more time intensive than a paper instruction treatment. Tang et al. (2003) however, did not find any statistical difference among the treatments when they measured time of completion.

Spatial Visualization Abilities

Spatial abilities are a component of human spatial cognition that can be utilized by AR to promote a deeper learning and understanding of concepts of learners with high and low spatial visualization abilities.

Human spatial cognition is fundamental to human life itself (Mark, 1993). Humans encounter numerous spatial concepts in their everyday lives: while walking on the street, driving cars, or navigating unfamiliar surroundings. As such, spatial concepts are often related to human cognitive infrastructure.



Figure 2.3 Map of spatial cognition, spatial abilities and spatial knowledge

The literature regarding spatial abilities is broad and applies to numerous fields (human-computer interaction, geography, cognitive and clinical psychology, human factors, etc.). After an initial literature review, it is evident that a hierarchy of spatial concepts that are pertinent to this AR study is critical. On top of the hierarchy is the spatial cognition. Spatial cognition is a crucial component of human intelligence, and it is included in several working memory models, such as Baddeley and Hitch's (1974) model of working memory. The structure of Baddeley and Hitch's (1974) memory model indicates that working memory consists of the phonological loop, episodic buffer, and the visual-spatial sketchpad. The visual-spatial sketchpad is responsible for remembering and processing information, such as colors, shapes, location, movement, navigation through complex environments (buildings, outdoors), as well as kinesthetic information (movement).

Further down the hierarchy are spatial abilities. The evidence for the connection between spatial cognition and spatial abilities was found by Miyake et al. (2001), who examined the relationship of visuo-spatial working memory (visual-spatial sketchpad in Baddeley & Hitch, 1974), executive functioning (central executive) and spatial abilities, and found that there is a strong connection between the three. Miller (as cited in Strong & Smith, 2001) noted that spatial cognition is the underlying mental process that allows an individual to develop spatial abilities. Eliot and Smith (1983) claimed that the term "spatial ability" has been defined in such a variety of ways that it is often difficult to be precise about the meanings that we ascribe to the term. However, Strong and Smith (2001) suggested that two main spatial factors consistently emerge from within the visualization discipline: (a) spatial orientation; and (b) spatial visualization. This study will focus only on spatial visualization.

McGee (1979) described spatial visualization as the ability to mentally rotate, manipulate, and twist two-dimensional and three-dimensional stimulus objects. Thurstone (as cited in Dunser et al., 2006) asserted that spatial ability is one of the most important components of human intelligence. Eliot (2002) argued that spatial intelligence is pervasive, and that it is necessary for almost every activity in everyday life. Wickens and Hollands (2000) also asserted that spatial visualization abilities are important, as they translate 2D images into 3D objects and mentally integrate them.

Another spatial construct that resides independently outside of the human spatial cognition infrastructure and spatial abilities is spatial knowledge. Shelton and Hedley (2002) noted that humans acquire knowledge about spatial phenomena by viewing 3D objects (landscapes) in their hands and that this type of knowledge queries happens every

day. Mark (1993) classified spatial knowledge according to its nature, sources of spatial information and human interaction with the world, and associated linguistic use. Only the relations of the first two classifications with human spatial cognition and abilities will be discussed in this research due to their logical connection with AR.

Mark (1993), Golledge and Stimson (as cited in MacEachren, 1991), and Wickens and Hollands (2000) first classified spatial knowledge based on the nature of spatial knowledge. This classification consisted of *declarative (landmark* knowledge in Wickens & Hollands, 2000), *procedural (route* knowledge in Wickens & Hollands, 2000) and *configurational (survey* knowledge in Wickens & Hollands, 2000) spatial knowledge. Declarative or landmark spatial knowledge is knowledge about objects and visual representations of the appearance of prominent landmarks (Mark, 1993; MacEachren, 1991; Wickens & Hollands, 2000).

Procedural spatial knowledge (also known as wayfinding and route knowledge), is considered to be at a higher level of cognitive development than declarative knowledge (MacEachren, 1991). Mark (1993) and MacEachren (1991) suggested that this type of knowledge is acquired by getting around our environment, and Wickens and Hollands (2000) added that this is a highly procedural verbal knowledge of how to get from one place to another.

The third type of spatial knowledge classified by its nature is configurational or survey spatial knowledge. Configurational spatial knowledge is at the highest level of cognitive processing and it is here that the understanding of spatial relationships occurs (MacEachren, 1991). Mark (1993) also stated that configurational spatial knowledge is "map like" in nature and often has or approximates a Euclidian geometry.

Shelton and Hedley (2004) claimed that AR interfaces are likely to constitute some combination of procedural (route) or configurational (survey) knowledge. It may be procedural because AR interfaces allow users to "fly into" the 3D display and experience it as if standing or moving inside a virtual world, and it may be configurational due to the interaction modalities where a user holds a 3D landscape in their hands like a map and views the entire geographical space in one view (Shelton and Hedley, 2004).

Mark's (1993) second classification of spatial knowledge was based on the sources of spatial information. Mark (1993) delineated cognitive sources of spatial information between haptic space, pictorial space, and transperceptual space. Haptic spaces are defined by tactile and kinesthetic sensory input; pictorial spaces are understood through visual perception; and transperceptual spaces are learned mostly through interface during wayfinding (Mark, 1993). Out of these three spaces, Mark (1993) asserted that sensorimotor and haptic perception are the most important early forms of spatial information that reaches the mind, and in many ways it is the most basic form. AR uses all three sources of spatial information compared to most other technologies that predominately operate in pictorial sources (pictorial modality). Shelton and Hedley (2004) noted that this combination of strong pictorial and strong haptic spatial knowledge that is acquired from interaction and manipulation offered by AR, may result in more rapid and more accurate perception.

Review of literature related to the influence of augmented reality on spatial visualization abilities. There are a limited number of research studies about human spatial cognition and spatial abilities literature that is related to AR. To substitute this lack of research literature, studies that focused on the influence of 2D and 3D images,

instructional video, virtual reality, animation, and problem solving on learners' visual spatial abilities were included in this study.

Shelton (2003) examined how learners change the way they come to understand topics that involve dynamic spatial relationships while interacting with virtual objects (AR). The content explored in this experiment was related to the earth-sun relationship (rotation/revolution, solstice/equinox, and seasons) and Shelton (2003) hypothesized that the AR interface would influence the way students come to understand earth-sun relationships. Shelton's (2003) study used quantitative statistical analysis for the first phase of the experiment (n=33), which included pre-test and post-test, Wilcoxon signed rank analysis, videotape analysis of student AR activity, analysis of pre-test and post-assessment interviews, and reflection interviews conducted three weeks after the initial exercise. To measure "more complete understanding", Shelton (2003) analyzed how the study participants interacted with the interface, their treatment of the content (before, during, and after the experiment), and drew upon the participants' metacognitive learning experiences. Study findings confirmed the original hypothesis and concluded that the AR interface indeed changed the way students understood the earth-sun relationship.

Shelton (2003) claimed first that instructional AR requires activity among participants for increased knowledge acquisition. Shelton's (2003) study was designed according to the constructivist learning approach where the instructor acts as a guide and the learner takes an active role in learning process. This way, the instructors were actively engaged with their students during the learning task and were able to guide them towards expertise or mastery. After analyzing a videotape of student activities, it became apparent

that the most successful students were also the most active, asked the most questions, and interacted with the AR markers the most.

Shelton (2003) further claimed that in his study, visuo-motor activity lead to expert knowledge of seasonal variation of light and temperature. Shelton (2003) pointed out that change in visual perspective proved crucial in regards to how the earth's axis remains at a consistent angle as Earth moves around the sun and that students claimed that having this control over what they saw proved extremely helpful in the learning process. In other words, more physical interaction led to better understanding, which is a claim also supported by studies by Jones et al. (2006), who found that hands-on tools made a difference during learning, and Persson et al. (2007), who found that haptic interfaces improved student understanding of the task.

The third claim by Shelton (2003) stated that blending of reality and virtuality holds unique advantages for teaching and learning. Shelton (2003) summarized this claim as follows:

This claim asserts that AR has unique properties for teaching and learning. The unique properties identified and analyzed here include (1) the ability to effectively communicate with reference to dynamic 3D objects, (2) the ability to regard virtual objects as both real and fake, and (3) that the "virtualness" of the objects affected how students experienced the content and therefore changed the way they learned it. The analysis supports the notion that mental representations of 3D events, when presented in 3D space, helped students gain a theoretically accurate understanding of Earth-sun relationships. (p. 281)

The Shelton (2003) study findings indicated that AR can be used in learning environments to influence and supplement students' spatial abilities and create a more comprehensive understanding of a given lesson. The addition of tactile manipulation (visuo-motor activity) of fiducial markers is linked to learning about dynamic spatial relationships and it can lead to better understanding of the content, as well. Additionally, adding another modality to learning has the potential to reduce cognitive load and help individuals learn better (Mousavi, Low, & Sweller, 1995). And lastly, promoting student interaction with the fiducial AR markers should lead to a deeper understanding of the lesson.

Furthermore, Hedley (2003) conducted a study that explores the acquisition and human processing of spatial knowledge. Hedley (2003) researched the impact that AR has on learner development of mental models of visual representations of spatial information that were mediated by different kinds of geographic visualization content and interface type. Geographic visualization content in this study included a geography lesson that was delivered via an AR interface (fiducial marker-based AR) and compared to a same lesson delivered on a desktop 3D interface in an experimental setting (n=101). Hedley (2003) measured user training, spatial abilities, user perception, judgment, and internalization during experimental activities and these dimensions provided data about the completeness and detail of a user's internal representations, speed and accuracy of timed and untimed spatial perception, and problem-solving tasks.

The results of this study indicated that AR interfaces provide advantages over desktop interfaces in a range of perceptual and task-based activities for users (Hedley, 2003). Like Shelton (2003), Hedley (2003) found positive differences for AR users in

task performance, task speed, completeness, and the level of detail to which he contributed to user's ability to directly manipulate 3D AR models. Wickens and Hollands (2000) also supported the notion that when the information is integrated into three dimensions, performance of tasks that require mental integration of information should also improve. From the cognitive load perspective, this work suggested that through multisensory interaction, the AR interface may indeed spread cognitive load for users, thereby reducing cognitive inertia (Hedley, 2003). In this case, the learners utilized tactile and visual sensory modalities, and since every modality has its own working memories, Mousavi, Low, and Sweller (1995) suggested that using multiple modalities can help individuals learn better and reduce cognitive load overall.

Shelton and Hedley (2002) examined the advantages of AR interfaces when viewing and manipulating 3D objects in a lesson about the earth-sun relationship. Researchers hypothesized that an AR interface would change the way students come to understand spatial knowledge in a whole new way. The study participants included 30 undergraduate geography students who were given a lesson on earth rotation and revolution, solstice and equinox, and seasonal variation of light and temperature. Researchers analyzed student performance change from pre-test to post-test, student score improvements, and for which topics the student performance was affected.

Quantitative statistical analysis yielded several trends. Shelton and Hedley (2002) reported that student expressions of their conceptual and factual understanding generally improved in all cases following AR intervention and that the largest increases in improvement were registered for those study participants with lower level pre-assessment scores. Qualitative analysis offered a view into the user experience while handling AR

content. Shelton and Hedley (2002) reported that less complex content seemed to be an effective way to introduce the AR interface and that the time it took to get used to the AR content was very short for most students. Researchers speculated that this was due to the fact that most students were familiar with complex 3D objects through their previous experiences with media and gaming (Shelton & Hedley, 2002). Shelton and Hedley (2002) also reported that the tangibility of virtual objects was so real for some students that they pointed and referred to the virtual objects during the exercise as if other people could see them the same way they could.

Similar to Shelton (2003) and Hedley (2003), this study also found that student understanding of a lesson improved following the AR treatment. One dimension that was not explored in all three studies (Shelton & Hedley, 2002; Shelton, 2003; Hedley, 2003) is whether AR can impact low spatial visualization learners in the same way it affects high spatial visualization learners and whether low spatial visualization learners can achieve the same scores as high spatial visualization learners. In another words, can AR be a "great equalizer" when it comes to learning spatial phenomena between learners with high and low spatial visualization abilities?

Summary of influence of augmented reality on spatial visualization abilities. In their exploration about how AR changes the human understanding of spatial phenomena, Shelton and Hedley (2002) found that AR reduced misinterpretations during learning and improved students' conceptual and factual understanding with most improvement for the study participants with lower level pre-assessment scores. They also noted that students often perceived AR 3D models as real and tangible.

Shelton (2003) concluded that AR holds the following unique advantages for teaching and learning: (1) the ability to effectively communicate with reference to dynamic 3D objects; (2) the ability to regard virtual objects as both real and fake; and (3) that the "virtualness" of the objects affected how students experienced the content and therefore changed the way they learned it.

And lastly, Hedley (2003) found that AR interfaces provide advantages over desktop interfaces (3D on a PC) in a range of perceptual and task-based activities for users, including task performance, task speed, completeness, and the level of detail to which he contributed these to the user's ability to directly manipulate 3D AR models. Hedley (2003) also suggested that through multisensory interaction, AR interface may spread cognitive load for users, thereby reducing cognitive inertia.

Review of literature related to the influence of visual modalities on spatial visualization abilities. The following six studies by Wang, Chang and Li (2007); Huk, Steinke and Floto (2003); Chen (2006); Yang et al. (2003); Cohen (2005); and Kozhevnikov, Motes, and Hegarty (2007) explore the influence of 2D, 3D, instructional video, VR, animation, and problem solving on learners' visual spatial abilities.

Wang, Chang, and Li (2007) explored the comparative effects of using web-based tutorials differentiated in including either 2D representation or interactive 3D representation on the influence of spatial visualization ability of undergraduate students. The Wang, Chang, and Li (2007) study used 23 undergraduate students, who were separated in two groups: 2D (n=10) and 3D (n=13). They were then presented with a web-based system that incorporated multiple media representations that were aimed at facilitating learners' spatial reasoning skills.

Statistical analysis yielded no statistical significance between students' pre-test and post-test scores on spatial visualization abilities, but Wang, Chang, and Li (2007) did observe a medium effect size for 3D group in terms of practical significance. The results of this study implied that different modalities of media representation (2D and 3D) are likely to influence students in different ways and Wang, Chang, and Li (2007) did call for a replication study due to their small sample size.

Huk, Steinke, and Floto (2003) investigated the influence of visual spatial ability on the attitude of users towards video and 3D animations in learning environments. Participants in this study included 125 biology students from high school and colleges in Germany, and were presented with the learning materials for a mitochondria and catabolic metabolism biology lesson. Participants were divided into two groups: biology lesson with QuickTime VR 3D models and the same biology lesson but without the VR models and with 2D images in place. Participants were given the Stumpf and Fay (Huk, Steinke, and Floto, 2003) spatial abilities test as well as the post-treatment likert scale survey that assessed learner attitudes.

Statistical analysis revealed that learner preference of the instructional treatment was indeed influenced by their spatial abilities. High spatial visualization ability learners showed a stronger preference towards the treatment that contained 3D materials. These findings were similar to findings reported by Cohen (2005) and Mayer and Sims (1994), who found that high spatial visualization learners preferred to use animation in order to fully comprehend the given problem. Huk, Steinke, and Floto (2003) suggested that preference for the simple mode of visualization by the low spatial visualization ability students may indicate that these learners may have suffered from cognitive overload after they were offered additional animations and videos (Chandler & Sweller, 1991). However, Betrancourt (2005) asserted that learners with low spatial visualization ability may benefit from animations because animations save learners from mentally simulating the functioning of the system. But this mental save may also induce shallow processing of the animated content, and consequently lead to what can be called "the illusion of understanding" (Betrancourt, 2005).

A study by Chen (2006) examined the effects that VR-based learning environments have on learners who possess different spatial abilities. Chen (2006) aimed to discover if there were any difference in test scores and interaction between learners with high and low spatial visualizations in three treatments: guided VR treatment (n=64), non-guided VR (n=58), and non VR treatment (n=58), which consisted of lectures and reading materials (control group). This study utilized 184 adolescents with an average age of 16.45. The students were divided into three different learning groups (guided VR, non-guided VR, and non-VR) and they were presented with a novice level car driver instruction lesson. This study utilized pre-test and post-test quasi-experimental design where the study participants were given content pre-tests. They also received the Bennett, Seashore, and Wesman Space Relations Test (Chen, 2006), as well as a 15-question posttest, which was designed to assess student understanding of the traffic rules.

Chen (2006) stated that the statistical analysis for the first three hypotheses that postulated that there is no significant difference in gained score for the VR-based tests between low, high, and low and high spatial visualization ability learners of each learning mode, revealed that a statistically significant difference in gain scores exists among the low and high spatial visualization ability learners in three groups. However, statistical

analysis also revealed that there were no significant score gains between the high and low spatial visualization abilities learners. When interpreting these results, one can conclude that spatial abilities did not play any role in these experiments, and that the only thing that mattered was the mode of content representation.

Yang et al. (2003) also investigated the impacts of animation on student learning and whether animation impact was determined by student spatial abilities. The participants were 415 undergraduate students enrolled in a first-semester introductory chemistry class. The experiment consisted of two treatments: computer animation treatment with 228 students, and still diagram treatment with 161 students. Each treatment group was taught by a tenured associate professor who lectured the students on the chemical concepts of how batteries generate electricity. Yang et al. (2003) used the 44-item American Chemical Society's California Chemistry Diagnostic Test as a baseline diagnostic test to assess student knowledge of chemistry, and two-one hour exams that were administered prior to the treatments. These exams were then used to analyze initial differences between the two treatment groups and also used as covariates in the analysis of the dependent measures. In addition, pre-test and post-tests were administered to measure the knowledge gains before and after the treatment, and the Purdue Spatial Visualizations test was given after the treatment to obtain a measure of students' spatial abilities.

Yang et al. (2003) found that students in instructor-led animation instructions performed better than students who were given static diagrams. For spatial abilities, researchers reported that animation was more helpful to students who possessed higher

spatial abilities. These results were consistent to those reported by Huk, Steinke, and Floto (2003), Mayer and Sims (1994), and Cohen (2005).

Cohen (2005) investigated the problem-solving strategies of learners with high and low spatial abilities. Study participants included six graduate students (three with high spatial abilities and three with low spatial abilities). The participants were screened for spatial abilities by using the Guay-Lippa Visualization of Viewpoints spatial abilities test and the Vandenberg Mental Rotation Test (Cohen, 2005). The experimental materials consisted of an egg-shaped figure with a transparent exterior that revealed an internal network of duct-like structures (Cohen, 2005). During the experiment, study participants had access to the two-user controlled interactive animations that offered 360-degree rotation around the horizontal axis and the egg-shaped stimulus. Study data was collected from the participants' use of available animation, coded verbal reports, and accuracy of the drawing task.

Study results indicated that high spatial ability students used the available animation more often than the low spatial ability students. In addition, high spatial abilities learners used more physical and spatial detail when explaining the details of the stimulus object and they drew more accurate representations of the intersection of the egg-shaped stimulus. The results of this study are similar to the Huk, Steinke, and Floto (2003), Mayer and Sims (1994), and Yang et al. (2003) studies, which found that animation led to better overall performance for high spatial ability learners.

Kozhevnkov, Motes, and Hegarty (2007) conducted three studies that examined the relations of spatial visualization to solve physics problems in the area of kinematics (an area of physics that describes the motion of objects in the terms of acceleration,
position, and velocity). The first study used 60 undergraduate students who had very little knowledge of physics. They were given a pre-test, a spatial abilities test based on the Ekstrom et al. (1976) Paper Folding Test, the Form Board Test, and a multiple choice kinematics test. The second study used 17 students, eight of which had high spatial ability and nine with low spatial ability. They were given the same problem as the students in the first experiment and they were also instructed to "think aloud" while solving the open-ended versions of the kinematics problems. Students were also videotaped to further analyze student interaction with the given physics problems. The third experiment used 15 undergraduate students (nine of which had high spatial ability and six with low spatial ability). They were given kinematics graph problems with 2D motion extrapolation problems. Kozhevnkov, Motes, and Hegarty (2007) used eye movement tracking (which was previously used to study visual imagery processes, mental rotations, mechanical reasoning, and graph comprehension) to analyze the differences in eye fixations of low and high spatial abilities students. To explain this eye tracking analysis, Spivey & Geng (2001) asserted that when viewing a static scene and imagining motion, human eye movement mimics the direction of imagined motion. The kinematics problems that the students received involved prediction of the motion of an object from an observed path (hockey puck and rocket problems), two graph problems, and one frame of reference problem that involved the translation from one system of reference to another. The first graph problem involved interpreting the movement depicted in a kinematics graph while the other involved relating a graph of one motion component to a graph of another motion component.

Results of all three studies concluded that a significant correlation exists between students' spatial abilities and the overall accuracy of their solutions to kinematics problems (Kozhevnkov, Motes, & Hegarty, 2007). Additional findings for the second study indicated that low spatial abilities students constantly neglected the importance of motion components. Kozhevnkov, Motes, and Hegarty (2007) suggested that they tend to choose those solutions that tax their visual spatial working memory less. The results of the third experiment explained the results of the previous two experiments. Eye tracking data for low spatial abilities students indicated that they did not account for the horizontal movement on one of the problems. Additionally, Kozhevnkov, Motes, and Hegarty (2007) pointed out that high spatial ability students spent more time analyzing the axis of the graph and integrating the motion of the object than low spatial abilities students who interpreted the graph as a literal representation of the object's motion. Findings of this study may have direct implications on scientific visualizations research with AR since AR would allow users to directly manipulate 3D representations of a problem and would eliminate the need for mental rotations of 2D content. This elimination of mental rotations could potentially equalize low and high spatial abilities learners.

A last study in the spatial visualizations abilities literature explored the potential of AR application to train spatial abilities (Dunser et al., 2006). The Dunser et al. (2006) study tested four interfaces on four groups. The first group was a Construct3D group (n=47) and it consisted of a 3D geometric construction tool that used collaborative AR setup with a see-through Head Mounted Display (HMD). The second group (n=44) used a CAD 3D program, which was a computer-aided design program with a computer monitor and mouse. The third and fourth groups were control groups. One control group

had geometry classes (n=66) in school and other did not (n=58). Dunser et al. (2006) could not find clear evidence on the effectiveness of AR as a spatial ability training tool. However, Dunser et al. (2006) argued that traditional spatial ability measurement does not cover all of the skills that are used when working in a 3D space. In other words, a new instrument must be developed to accurately measure gains in spatial ability training (Dunser et al., 2006). Dunser et al. (2006) further suggested that AR can be used to develop useful tools for spatial ability training.

Summary of influence of visual modalities on spatial visualization abilities.

Visual modes of information representation, such as 2D (images animation and video) and 3D, influence people with high and low spatial abilities differently (Wang, Chang, & Li, 2007). Studies by Huk, Steinke, and Floto (2003), Cohen (2005), Kozhevnkov, Motes, and Hegarty (2007), and Yang et al. (2003) all indicated that the learner's preference for the visual instructional treatment (2D and 3D) is influenced by the learner's spatial abilities. In these studies, it was found that learners with high spatial visualization abilities prefer animation and 3D learning materials over 2D instructional materials. High spatial visualization learners were able to extract more information from such media and could describe the content in more details. Students with low spatial visualization abilities were attracted to the simple 2D instructional materials, such as imagery, and were generally less inclined to utilize 3D content. Huk, Steinke, and Floto (2003) noted that this attraction to the simple modes of visual representation may indicate high cognitive load in low spatial visualization learners when using more complicated modes of representation, such as 2D animation and 3D content.

Summary of spatial visualization abilities. The most recurrent concept that was researched in the reviewed literature was the influence of 2D, 3D, instructional video, VR, animation, and problem solving on learners' visual spatial abilities. Huk, Steinke, and Floto (2003), Kozhevnkov, Motes, and Hegarty (2007), Yang et al. (2003), and Cohen (2007) found that the mode of representation did indeed have an impact on spatial visualization abilities, and learners with high spatial visualization abilities generally preferred 3D and animation-based instructional materials compared to 2D images and graphs. Kozhevnkov, Motes, and Hegarty (2007) pointed out that learners with low spatial visualization abilities simply chose ignore the importance of crucial motion components in kinematics experiments, and this was most likely because these extra bits of information were taxing their working memory (Huk, Steinke, & Floto, 2003). According to Baddeley and Hitch's (1974) working memory model, the visuo-spatial sketchpad is where humans process visual and spatial stimuli and its capacity varies from person to person. Kozhevnkov, Motes, and Hegarty (2007) asserted that "people who differ in spatial abilities also differ in performance on laboratory spatial imagery tasks such as mental rotation (e.g., Carpenter et al., 1999) and measures of spatial working memory (e.g., Salthouse et al., 1990; Shah & Miyake, 1996)" (p. 576), but these differences can be ameliorated with rich visualization technologies, discussed by Kozhevnikov and Thornton (2006). AR falls under the category of rich visualization technology since it can display 3D models, and with the addition of tactile sensory modality, it may increase cognitive processing of learners with low spatial visualization abilities.

Two studies by Chen (2006) and Chen, Wang, and Chiang (2009) reported that spatial abilities did not play a significant role in learning. However, Chen (2006) did find that guided AR instruction did lead to better learning, which was similar to the finding of Yang et al. (2003), which stated that instructor-led animations gave better learning results than static diagrams. Moreno and Mayer (2005) and Rieber (2005) reported similar findings and they pointed out that guidance through the learning activity is required.

Shelton and Hedley (2002), Shelton (2003), and Hedley (2003) explored how AR changes the human understanding of spatial phenomena. Shelton and Hedley (2002) found that AR reduced misinterpretations during learning and improved student conceptual and factual understanding with most improvement for the study participants with lower level pre-assessment scores. Shelton and Hedley (2002) noted that students often thought of AR models as real, tangible models and some students referred to the virtual objects during the exercise as if other people could see them the same way they could. Additionally, Shelton (2003) concluded that AR holds the following unique advantages for teaching and learning: (1) the ability to effectively communicate with reference to dynamic 3D objects; (2) the ability to regard virtual objects as both real and fake; and (3) the "virtualness" of the objects affected how students experienced the content and therefore changed the way they learned it.

Hedley (2003) found that AR interfaces provide advantages over desktop interfaces (3D on a PC) in a range of perceptual and task-based activities for users, such as task performance, task speed, completeness, and the level of detail to which he contributed these to users' ability to directly manipulate 3D AR models. From the cognitive load perspective, Hedley (2003) suggested that through multisensory

interaction, AR interface may spread cognitive load for users, thereby reducing cognitive inertia.

Tactile and Kinesthetic Sensory Input

The feeling of touch is a very intuitive human sensation that does not need interpretation (Nojima et al., 2002). Jones et al. (2006) described touch as an active discovery sense. Several researchers claim that handling objects is a more effective way for students to learn complex and abstract science concepts when compared to more passive modes of instruction (Druyan, 1997; Glasson, 1989; Vesilind & Jones, 1996). Tactile and kinesthetic sensory inputs are key features of fiducial-based AR because this type of AR requires active user involvement, which includes manipulation of fiducial markers.

As discussed earlier, Baddeley and Hitch's (1974) proposed a model of working memory, which is comprised of central executive, phonological loop, episodic buffer, and visuo-spatial sketchpad. It is in the visuo-spatial sketchpad where humans process visual information. Logie (1995) categorized the visuo-spatial sketchpad into two components: the visual cache, which stores information about color and form; and the inner scribe, which processes spatial and movement information. And in his more recent writings, Baddeley (2007) described the visuo-spatial sketchpad as a "subsystem that has evolved to provide a way of integrating visuospatial information from multiple sources, visual, tactile and kinesthetic, as well as from both episodic and semantic long-term memory" (p. 101). This architecture is supported by the CLT, which is built on an assumption that human memory is limited, and that for efficient cognitive processing to take place, learners should be exposed to optimal levels of cognitive load (Sweller, 1994). Auditory and visual modalities have their own working memories (phonological loop and visuo-

spatial sketchpad) with the abilities to integrate information from multiple sources, such as visual, tactile, and kinesthetic (Baddeley, 2007). Mousavi, Low, and Sweller (1995) suggested that using multiple modalities can help individuals learn better and reduce the cognitive load. Following this logic, one can reduce the cognitive load and promote deeper learning by using tactile in as well as visual and/or auditory information during a lesson.

Marshall (2007) discussed several benefits of using tangible interfaces during learning: (a) using physical materials in learning might change the nature of knowledge gained compared to knowledge gained through interaction with virtual materials; (b) tangible interfaces may support more natural learning through tactile interaction; (c) tactile interaction is assumed to be more natural; and (d) tangible interfaces may be useful in collaborative learning. Using tactile and kinesthetic information during learning is a common concept that reappears in the reviewed literature (Jones et al., 2006; Marshall, 2007; Fjeld et al., 2002). As a technology which offers tactile modality, AR has great potential to be used to enhance learning and as such should be researched further.

Review of literature related to the influence of tactile sensory modality on learning with augmented reality. Fjeld et al. (2002) compared a Tangible User Interface (AR application) that was designed in-house, with two alternative single-user tools that consisted of a 3D physical model and a 2D cardboard model of spatial laser-positioning problem. In this experiment, Fjeld et al. (2002) measured trial time to complete the task, number of user operations (cognitive support), learning effect in both preceding variables (cognitive support), and user satisfaction. Thirty undergraduate students were used for

this study (13 females, 17 males, age 20-26) and 10 participants were assigned to each treatment (physical model, AR, and cardboard).

Results of this study indicate that the physical 3D tool significantly outperformed the 2D cardboard treatment in the time it took the participants to complete, as well as cognitive support. Additionally, the physical 3D tool also outperformed the AR tool, but only in user satisfaction, while the time-to-complete difference was not statistically significant (Fjeld et al., 2002). Some considerable, but not statistically significant, learning effects were observed with the AR tool during the trial time and the amount of blocks tested (Fjeld et al., 2002). This study frames AR as a viable alternative to physical 3D tools/models. Considering the cost of producing such 3D physical tools/models, such as process models or simple physical 3D objects (e.g., fire truck or a warehouse), AR could dramatically lower the cost of learning materials while still delivering the cognitive support offered by learning materials that offer tactile modality.

Review of literature related to the influence of tactile sensory modality on learning with haptic devices. A study by Minogue et al. (2006) explored the impact of haptic augmentation on middle school students' conception of the animal cell. Minogue et al. (2006) utilized a pre-test and post-test control group design in which the participants (n=80) were randomly assigned to one of the two treatment groups (n=40 per group). Both groups used the same learning content (cell exploration), but delivered with different modalities. The first group received two modality instructions (visual and haptic) while the control group only received the lesson delivered in visual modality. According to Minogue et al. (2006), the cell exploration program placed the student into

a semi-immersed environment and it allowed the student to interact with the learning content (rotate and zoom).

Study results indicate that there were significant differences in pre-test and posttest scores on all cognitive items and that learning did occur (Minogue et al., 2006). It appears that the students benefited from the affect. The affect was influenced by haptic feedback, which has been shown to have a positive impact on user interest, attitudes, and the ability to navigate in 3D environments (Minogue et al., 2006). Researchers did not find any impacts on participants' cognition due to the intentional limitations imposed by some of the assessments used in the study, but they did speculate that the given lesson created increased extraneous cognitive load due to content complexity, and because of the haptic interface, which was new to most students. Minogue et al. (2006) suggested further exploration of haptic interfaces, how they impact learners cognitively and affectively, and how students perceive, process, store, and make use of haptic information in various educational concepts.

Similar to Minogue et al. (2006), Jones et al. (2006) investigated the impact of haptic augmentation of science inquiry program and how addition of haptic feedback influenced the student learning experience. Thirty-six middle and high school students participated in this study and were randomly assigned to three tangible interface groups: computer mouse, Sidewinder joystick, and PHANToM haptic device. Jones et al. (2006) wanted to determine if there were any differences by instructional treatment for the students' knowledge of virus characteristics and student attitudes towards the instructional treatment.

Research results suggest that hands-on tools and the addition of tactile modality in general, do indeed make a difference in student learning. Researchers also reported that more sensitive haptic tools resulted in better virus descriptions by the students and that haptic tools provided a more immersive and engaging environment (Jones et al., 2006). Jones et al. (2006) proposed that the results of this study provide indirect support for Paivio's (1986) dual coding theory and Sweller's (1994) CLT, which both suggest that visual and auditory information are processed in their own channels in working memory, and that adding multiple channels or modalities (visual, tactile, auditory) to the instructional materials can reduce the cognitive load on students (Mousavi, Low, and Sweller, 1995). This study proposes that haptic augmentation of science visualizations has the potential to expand student learning and offer new ways to interact with the learning materials.

Persson et al. (2007) presented an evaluation of a haptic system to determine the benefits that haptics can have on biomolecular educational context. This study utilized 23 students (13 female and 10 male), who were divided into two groups and given a lesson on protein-ligand docking. The first group had the haptic device turned on while the other group had the haptic device turned off during the experiment. Researchers used cognitive knowledge tests and interviews to assess any potential knowledge differences between the two groups.

Study results indicate that there was no obvious advantage from adding force feedback to the lesson. However, researchers reported that haptics did successfully convey the importance of forces in understanding the biomolecular lesson (Persson et al., 2007). Qualitative statistical analysis of student interviews indicated that the use of haptic

instruments helped some students understand the forces involved and better comprehend the biomolecular models. For future research, Persson et al. (2007) expected to study how VR helps students understand the subject matter and how a learner's spatial abilities might help him/her navigate the 3D content.

Summary of influence of tactile sensory modality on learning with haptic devices. All three studies in this section found that learners benefited from the use of haptic devices to varying degrees. Minogue et al. (2006) found that learners benefited from the affective properties of haptic devices and that haptic devices incited interest, influenced attitudes towards learning, and enhanced learner's abilities to navigate 3D environments. Jones et al. (2006) reported that hands-on tools made a difference on learning. In addition, the sensitivity of haptic tools helped students explain the instructional content in more detail. Lastly, Persson et al. (2007) reported that haptics did not play a significant role when added to the lesson, but haptics did convey the importance of forces in a biomolecular lesson, decreased the overall lesson completion time, and improved understanding.

Review of literature related to the influence of tactile sensory modality on learning with physical and virtual instructional content. The following two studies by Triona and Klahr (2003) and Klahr, Triona, and Williams (2007) examined the use of physical learning materials during learning and compared them with their software equivalents. In the first study, Triona and Klahr (2003) compared two instructional conditions that only differed by delivery method. The first condition used physical springs and weights and the students were required to handle them, while the second condition was in the form of the software simulation of springs and weights. Study

participants were 92 fourth and fifth grade children, who were taught how to design an unconfounded experiment by using one of two instructional methods. To gather data for this experiment, researchers used a three-phase factorial design: pre-test and training, post-test, and transfer to measure students learning (Triona and Klahr, 2003).

The results of this study indicated that there was no significant statistical difference between the group who interacted with the physical learning materials and the group that completed their work on the PC, as students in both treatments all made large gains in knowledge (Triona and Klahr, 2003). Authors suggested that replacing the physical materials with virtual materials does not affect the amount of learning transfer when aspects of the instruction are preserved. In this case, all aspects of instruction were preserved, as the virtual lesson had successfully captured the important features of the physical interaction (Triona and Klahr, 2003). For future research, Triona and Klahr (2003) proposed to examine if there are any differential effects of media for different types of tasks and what other domains will show equivalence between the instructional efficacy of physical and virtual materials when methods are carefully controlled.

A follow-up study by Klahr, Triona, and Williams (2007) extended the Triona and Klahr (2003) study in several ways. First, Klahr, Triona, and Williams (2007) used discovery context over direct instruction. Discovery context allowed the researchers to focus on domain-specific knowledge, which would have impact on more pronounced differences between physical and virtual materials (Klahr, Triona, & Williams, 2007). Secondly, Triona and Klahr (2003) used fourth and fifth graders who may have been too young for the task presented and whose cognitive capacities may have overwhelmed the potential impact of differences between instructional materials. Klahr, Triona, and

Williams (2007) used 56 seventh and eighth graders (20 girls and 65 boys; M=13.1 years, SD=0.69 years) for this study because it was estimated based on lessons learned in the Triona and Klahr (2003), that that their cognitive abilities should be able handle the complexity of the presented lesson. Lastly, Klahr, Triona, and Williams (2007) instructed their subjects to discover the knowledge in the lesson presented, which is in contrast to Triona and Klahr (2003), who taught their students domain-general procedural knowledge about how to design unconfounded experiments. The purpose of the Klahr, Triona, and Williams (2007) study was to determine the effects of putting learners hand on virtual rather than physical materials in a scientific discovery context. For their experiment, Klahr, Triona, and Williams (2007) used physical and virtual mousetrap cars. Study participants were divided into two groups (physical and virtual lesson), and tested with a fixed amount of time and a fixed amount of cars they could construct.

Results of the study were very similar to Triona and Klahr's (2003) results, as all four conditions were equally effective in producing significant gains in learners' knowledge about casual factors, in their ability to design optimal cars, and in their confidence of their knowledge. One factor that was statistically significant was time; children constructed significantly more cars in a virtual environment for the same block of time allocated for the physical treatment. Additionally, children also completed the task in less time in the virtual environment compared to the physical environment, when asked to build just six cars. Klahr, Triona, and Williams (2003) noted that the most surprising discovery of their study was the fact that a physical–virtual distinction had no effect on the quality of children's answers to the final open-ended questionnaire item ("What else do you think would be important for building a distance car?"). While the

children in the physical mousetrap car assembly group experienced crooked car paths, unwinding strings, tight wheels that caused high friction, the children in the virtual group did not experience any of these issues. Klahr, Triona, and Williams (2007) expected the children in the physical group be more experienced, with a deeper, nuanced understanding of the underlying physics of the mousetrap cars, but the analysis of the final questions did not support this hypothesis. As a final remark, Klahr, Triona, and Williams (2007) asserted that much remains to be learned about learning efficiency of physical and virtual learning materials when they are used in different domains, with different instructional goals, outcome measures, and types of students.

Review of literature related to the user perceptions and interaction with tactile augmented reality interface. Hornecker and Dunser (2009) completed a study on the use of AR "Magic Book" and how young children reacted and interacted with the physical objects that were augmented with digital 3D objects. Researchers designed two "Magic Book" stories, which were essentially a combination of physical paper pages and desktop interactions (screen and mouse), which replaced traditional narrated text pages with animated interactive sequences. During these interactive sequences, children were required to manipulate paddles with AR fiducial markers and control the story's main characters by physically moving the paddles. Hornecker and Dunser (2009) expected the children to behave intuitively with the paddles, as using physical paddles for virtual content enables people to use skills they have developed throughout their lives to manipulate real objects. This notion is commonly referred to as "affordances" and had been introduced to the area of human-computer interaction by Norman (1988). Norman (1988) described affordance as perceived and actual properties of an object, especially

fundamental properties that determine just how the thing could possibly be used. Norman (1988) gave several examples of affordances, a chair affords support and therefore affords sitting, but it can also be carried. Hornecker and Dunser (2007) expected the children to utilize the given paddles as affordances; it was expected that they would hold the paddles in the way they should be held, thereby decreasing the time it took to become familiar with the system, and to become almost an extension of their hands during the interaction with the AR 3D models. Participants in this study were children (ages six to seven), who were divided as follows: four pairs and three children experimented with the "Sun" story, and 10 pairs and three individual children experimented with the "Chick" story.

One of the main findings in this study was that children who worked collaboratively took less time and showed more signs of enjoyment, such as laughter and general play (Hornecker & Dunser, 2009). Researchers also found that the children expected digital augmentations to behave as real objects. Affordances offered by the paddles that became physical interaction devices between the AR and physical worlds, invited actions that were not accounted for by the designers of the system. The interaction became so real to them that the children often expected virtual 3D objects to behave according to the rules of the real world. As a final thought, Hornecker and Dunser (2009) discovered that it is not always evident how users will perceive and interpret physical input opportunities since everyone is unique when it comes to life experiences. Users of the system may completely misinterpret the physical interface and utilize it in a way that was not anticipated by the system designers, because richness of interactions may lead to high variability.

Summary of tactile and kinesthetic sensory input. Empirical research-based literature that focuses on comparison between hands-on (tactile) learning with learning using computer-based instruction (software, AR, VR) is limited. To supplement this lack of studies, this researcher added several studies in the area of haptics research since haptics are closely related to the representation of tactile sensory information. The following summary of findings is categorized into studies that focus on influence of tactile sensory modality on learning with AR, haptics, physical hands-on exercises, and user perceptions and interactions with tactile AR interfaces.

Fjeld et al. (2002) compared a physical model with AR and cardboard instructional material and concluded that physical tools outperformed AR in terms of user satisfaction, but it offered the same cognitive support. This result has significant implications on the cost effectiveness of producing training material, as 3D models may be considerably cheaper to create than their physical equivalents. Hornecker and Dunser (2009) explored how children perceive and interact with AR 3D models and found that children who worked collaboratively took less time and showed more signs of enjoyment, such as laughter and general play (Hornecker & Dunser, 2007). In addition, researchers found that children perceived 3D models as real and they expected them to behave the same way as physical models. This tangibility was further researched by Shelton (2003), who found that AR often requires physical (tactile) interaction among participants for increased knowledge acquisition. Shelton (2003) also found that visuo-motor activity offered by AR interface in his study led to expert knowledge of seasonal variation of light and temperature. Furthermore, Peruch, Vercher, and Gauthier (1995), Yim and Seong

(2010), and Dunleavy, Dede, and Mitchell (2009) found that participants performed better when engaged in physically active exploration.

In an area of haptics research, Minogue et al. (2006) found significant differences in student learning when haptics were used during instruction. Students benefited from affective benefits created by haptics and expressed interest, positive attitudes, and increased ability to navigate 3D environments. Researchers did not find evidence of increased or decreased cognitive support offered by haptics, but the tools used to measure cognitive effort were intentionally limited due to time restrictions. Jones et al. (2006) reported that the addition of hands-on tools and haptics positively influenced learning and that the sensitivity of haptics tools provided more of an immersive environment. Jones et al. (2006) linked the findings to Paivio's (1986) dual coding theory and CLT, which both imply that using multiple modalities, such as visual, tactile, and auditory, can reduce the cognitive load on students. A study by Persson et al. (2007) found no obvious advantage from adding a force feedback in pre-test and post-test analysis, but researchers did report that haptics successfully conveyed the importance of forces during a biomolecular lesson. Additionally, several study participants in Persson et al. (2007) reported that haptic feedback helped them create a more complete picture of the studied subject.

Triona and Klahr (2003) and Klahr, Triona, and Williams (2007) conducted studies that compared physical learning materials to each other and with their software equivalents on a PC, and found no significant differences in student learning. The authors suggested that replacing the physical materials with virtual materials does not affect the amount of learning transfer when aspects of the physical instruction are preserved. The only dimension in which Klahr, Triona, and Williams (2007) did find statistically

different was completion time, as children constructed more cars in the software version of the task. Deeper understanding that was expected to come with physical interaction also did not play significant role on post-tests. Klahr, Triona, and Williams (2007) noted that much remains to be learned about learning efficiency of physical and virtual learning materials when they are used in different domains, with different instructional goals, outcome measures, and types of students.

General Summary of the Review of the Literature

Augmented reality interface comparison, learning with augmented reality and learner's attitudes toward virtual reality. Literature reviews by Yu et al. (2010) and Van Krevelen and Poelman (2010) argued that AR as a technology has a bright future, but first it must overcome several obstacles, including hardware limitations (speed of processing, portability, and limited HMD devices), position tracking, advanced occlusion detection, and development of intelligent recognition systems. Educational applications of AR are still in their infancy stage (Kerawalla et al., 2006), but research is available in three major areas in which AR has potential to grow: reduction of cognitive load during learning, influence of learner's spatial visualization abilities, and the ability of AR to offer tactile modality. The following section will focus on the influence of AR on the reduction of cognitive load and implications of AR in learning.

Review of the general AR literature reveals several tracks in the areas of cognitive load, learning, user satisfaction, motivation and interest, and task completion time. In cognitive load research, Tang (2003), Haniff and Baber (2003), and Wang and Dunston (2006) found that HMD AR interface reduced cognitive load in study participants when compared to other interfaces, such as paper instructions, CAI on LCD monitors, and AR

on LCD monitor, while Juan (2008) found no significant statistical difference between the HMD and LCD monitors. Klatzky et al. (2008) found that AR reduced the need for spatial visualizations, thus reducing the cognitive load. Kim and Dey (2009) found that an AR interface reduced cognitive load by eliminating divided attention (split attention effect in CLT) during a driving lesson for elderly drivers, and Hedley (2003) reported that AR can spread the cognitive load for users, thereby reducing cognitive inertia. However, Dunleavy, Dede, and Williams (2009) indicated that AR may have increased cognitive load due to the inadequate training of study participants. Chen, Wang, and Chiang (2009) did not find any significant statistical difference between users with low and high cognitive load. To summarize the effects of AR on cognitive load, the reviewed literature definitely implies that that AR may be used to decrease cognitive load during learning.

From a learning perspective, most studies reported that AR positively influenced learning. Vilkoniene (2009) reported that when used with traditional teaching methods, such as printed materials and in-class lecture, AR positively influenced student learning. Leblanc et al. (2010), in their AR interface study, reported higher post-test scores with AR, and Tang et al. (2003) reported that AR reduced the number of task errors during an assembly task. Additionally, Klatzky et al. (2008), Tang et al. (2003), and Yim and Seong (2010) noted increased task accuracy. The Dunleavy, Dede, and Williams (2009) study concluded that that students thought that learning with AR was authentic, effective in engaging disengaged students, and introduced a novel way to teach math. Additionally, Dunleavy, Dede, and Williams (2009) and Huang, Rauch, and Liaw (2010) reported that collaborative learning lessons with AR increased student motivation and problem-solving

skills. Furthermore, Blake and Butcher-Green (2009) explored adaptive scaffolding and whether people learned better when it was used. They found statistically significant differences between the two groups, in favor of adaptive scaffolding. And lastly, Hsiao et al. (2010) compared AR learning systems that included physical exercise with classroom instruction and found no significant difference between the two.

User satisfaction was also a dimension explored by Juan, Beatrice, and Cano (2008), Haniff and Baber (2003), and Leblanc et al. (2010). Juan, Beatrice, and Cano (2008) reported that study participants liked both AR and HMD AR systems, while Haniff reported that students preferred AR treatment over paper treatment. However, Leblanc et al. (2010) did report higher user satisfaction when students interacted with the physical treatment (cadaver).

Learner motivation and interest were examined by Huang, Rauch , and Liaw (2010), Dunleavy, Dede, and Williams (2009), and Yim and Seong (2010). Huang, Rauch, and Liaw (2010), and Dunleavy, Dede, and Williams (2009) reported that learner motivation and problem solving increased with the use of AR. Yim and Seong (2010) reported that learning efficiency was increased in students because AR generated high interest in students.

Haniff and Baber (2003), Tang et al. (2003), and Wang and Dunston (2006) also examined the time it took to complete the task. Wang and Dunston (2006) found that when compared to the traditional LCD monitor, HMD reduced the amount of time to complete the task. Haniff and Baber (2003) found that the AR treatment was slower than the paper instruction task, while Tang et al. (2003) did not find any statistical difference in time completion.

Spatial visualization abilities. Review of the human spatial cognition and spatial visualizations literature indicated several trends: influence of visual modalities such as 2D, 3D, VR, animation, video and problem solving on human spatial visualization abilities and learning and influence of AR on human understanding of spatial information.

Studies that focused on the influence of visual modalities on human spatial visualization abilities were performed by Huk ,Steinke, and Floto (2003), Kozhevnikov, Motes, and Hegarty (2007), Yang et al. (2003), and Cohen (2007). They determined that the mode of representation can impact visualization abilities. It was also concluded that high spatial visualization learners prefer 3D and instructional materials with animation over 2D images and were able to extract more information from such representations. Kozhevnikov, Motes, and Hegarty (2007) pointed out that learners with low spatial visualization abilities often chose not to include additional movement in the given experiments into their mental calculations, which was confirmed by eye tracking tests. Kozhevnikov, Motes, and Hegarty (2007) asserted that the reason for this was most likely because these extra bits of information were taxing their working memory (Huk, Steinke, & Floto, 2003). However, in another study, Kozhevnikov and Thornton (2006) claimed that the differences between learners with high and low spatial abilities can be equalized by rich media technologies. In their research, Klatzky et al. (2008) also confirmed this and concluded that AR can reduce the need for spatial visualizations in learners with low spatial visualization abilities.

Chen (2006) and Chen, Wang, and Chiang (2009) found that learners' spatial abilities did not play a significant role during learning, but Chen (2006) did find that

guided AR instruction led to better learning. This finding was similar to Yang et al. (2003), who found that instructor-led lessons that included animation yielded better scores than lessons that incorporated static 2D diagrams. Similar findings were also reported by Moreno and Mayer (2005) and Rieber (2005).

Three studies that explored how AR changes the human understanding of spatial phenomena were performed by Shelton and Hedley (2002), Shelton (2003), and Hedley (2003). Shelton and Hedley (2002) found that AR reduced misinterpretations during learning and improved conceptual and factual understanding in students overall. Similar to Hornecker and Dunser (2009), Shelton and Hedley (2002) reported that students viewed AR 3D models as tangible and real, and that they preferred simple models like those reported by Huk, Steinke, and Floto (2003).

Shelton (2003) reported that AR offers three unique advantages that makes it suitable for teaching and learning: (1) AR has the ability to effectively communicate with reference to dynamic 3D objects; (2) AR has the ability to regard virtual objects as both real and fake; and (3) "virtualness" of the 3D objects represented via AR affected how students experienced the content and therefore changed the way they learned it. Additional advantages of the AR interface over desktop interfaces, such as 3D on a computer, include for a range of perceptual and task-based activities: task performance, task speed, completeness, and the level of detail to which Shelton (2003) contributed these to user's ability to directly manipulate 3D AR models.

Tactile and kinesthetic sensory input. Due to the limited number of studies that focus on the tactile effects of AR on learning, the search for literature to include research studies on haptics and physicality comparison studies was expanded. Fjeld et al. (2002)

compared physical models to AR 3D models and cardboard instructional material and concluded that physical tools outperformed AR only in terms of user satisfaction. Hornecker and Dunser (2009) researched how children perceive and interact with 3D AR models and found that children who worked collaboratively took less time to complete related tasks and showed more signs of enjoyment, such as laughter and general play. Additionally, similar to Sheldon and Hedley (2002), Hornecker and Dunser (2009) reported that children perceived 3D models as real.

Minogue et al. (2006) reported significant differences in student learning when haptics were used during the instruction. Students benefited from affective benefits created by haptics and expressed interest, positive attitudes, and increased ability to navigate 3D environments. Research by Jones et al. (2006) also indicated that the addition of hands-on tools and haptics positively influenced learning, and that the sensitivity of haptics tools provided more of an immersive environment for learners. A study by Persson et al. (2007) found no obvious advantage from adding a force feedback in pre-test and post-test analysis, but researchers did report that haptics did successfully convey the importance of forces during a biomolecular lesson. Additionally, several study participants reported that haptic feedback helped them create a more complete picture of the studied subject (Persson et al., 2007).

The Triona and Klahr (2003) and Klahr, Triona, and Williams (2007) studies compared physical learning materials with their software equivalents on a PC and found no significant differences in student learning. The authors suggested that replacing the physical materials with virtual materials did not affect the amount of learning transfer when aspects of the physical instruction were preserved. The only dimension that Klahr,

Triona, and Williams (2007) did find statistically different was productivity. The children constructed more cars in the software version of the task than the children who used the physical models. Deeper understanding that was expected to come with physical interaction also did not play a significant role on post-tests. Klahr, Triona, and Williams (2007) admitted that much remains to be learned about learning efficiency of physical and virtual learning materials when they are used in different domains, with different instructional goals, outcome measures, and types of students.

General Conclusions

AR is a new technology that still hasn't reached its full potential, especially in education. Research of AR applications in education was not extensive enough during the past 10 years to create a large body of knowledge that is often an indicator of a mature academic or technological field. To contribute to this field further, academic research that examines interaction between AR and cognitive load, human spatial visualization abilities and tactile sensory input, is required.

The dominant theory used to examine reviewed literature is the CLT, which predicts the learning outcomes and provides guidelines that assist in presentation of information by taking into considerations the human cognitive architecture. CLT promotes a decrease of extraneous cognitive load, which is often caused by improperly designed learning materials; intrinsic cognitive load, which is associated with the difficulty of learning content; and increase of germane cognitive, load which is associated with knowledge (schema) construction. From the CLT perspective, AR has the potential to reduce the extraneous and intrinsic cognitive loads, and promote germane cognitive load. AR can reduce extraneous cognitive load by representing visual information (3D) in

a way that promotes the use of human spatial visualization abilities. Research has shown that two-dimensional representations of information provide the necessary information to construct three-dimensional information which is more compatible with human mental model of the three dimensional world, but they require mental effort (Wickens & Hollands, 2000). Providing full representations with integrated information (3D) may allow AR to reduce extraneous and intrinsic cognitive load, which in turn will relieve the working memory load and allow learners to direct the additional working memory resources to germane processing.

Since information processing is performed in a working memory, a model of working memory is necessary to explain the implications that AR has on human cognition. The model of human cognitive infrastructure that is used in conjunction with the CLT to explain the effects of various interactions between the instructional materials and human cognition is Baddeley and Hitch's (1974) model of working memory. This memory model consists of a phonological loop, visuo-spatial sketchpad, episodic buffer, and central executive. The focus of this research study is the visuo-spatial sketchpad component, which is responsible for the integration of visuospatial information from multiple stimuli sources (visual, tactile, and kinesthetic), as well as from both episodic and semantic long-term memory (Baddeley, 2007).

The visuo-spatial sketchpad is closely related to the spatial abilities (spatial orientation and spatial visualizations) that are an essential component of human intelligence. Since AR is mostly visual and tactile modality, this research study focuses on the spatial visualization abilities only because of their close relation with the processing of visual stimuli. Spatial visualizations enable us to mentally rotate,

manipulate, and twist two- and three-dimensional stimulus objects (McGee, 1979) and they are essential when used to explain the influence of AR on human learning.

Literature reports that AR (3D) and similar visual modes of representations, such as 2D, VR, animation, and video, can influence spatial visualization abilities (Cohen, 2005; Yang et al., 2003; Kozhevnikov, Motes, & Hegarty, 2007; Huk, Steinke, & Floto, 2003). Kozhevnikov, Motes, and Hegarty (2007) also reported that AR can expand spatial visualization abilities, and reduce the need for spatial visualizations. Reduction of spatial visualization can positively influence learners who possess low spatial visualization abilities and may bring them closer in terms of how well they learn to learners with high spatial visualization abilities. Lastly, AR can reduce information misinterpretations by depicting fuller representations of integrated information to the point that it can be confused with physical objects.

The visuo-spatial sketchpad is also responsible for processing tactile information, which is the last dimension of AR examined in this research study. It is suggested that tactile information is an active discovery sense (Jones et al., 2006). From the CLT perspective, tactile information is an additional modality that can be used with visual or auditory modalities to aid in the reduction of overall cognitive load (Mousavi, Low, & Sweller, 1995).

Literature review reports on the influence of tactile modality during learning are mixed. AR literature reported that AR was very close to physical modality in both perception (Fjeld et al., 2002; Hornecker & Dunser, 2009) and learning (Fjeld et al., 2002). Haptics literature reported that the addition of tactile modality aided student learning (Minogue et al., 2006; Jones et al., 2006). Persson et al. (2007) did not find that

haptics influenced learning, however, but they did find that it contributed to the creation of a more complete picture of the studied subject. Lastly, research that compared physical hands-on learning with its software equivalent on a PC did not find any significant differences between the treatments.

Research Implications

Further examination of AR from the perspectives of cognitive load, spatial abilities, and tactile sensory input is needed. There are other concepts and properties related to AR, but these three are most commonly mentioned in the context of AR and learning.

Research of AR interfaces (HMD and LCD monitor) indicates that AR-based 3D models can reduce cognitive load by eliminating the need to mentally construct and manipulate objects. This mental construction and manipulation is common when learners interface with other traditional learning materials, such as paper instruction or instructional video. Research indicates that this mental manipulation can increase learner's cognitive load. One of the benefits of reduced cognitive load is improved learning. As Van Merrienboer et al. (2002); Tabbers, Martens, and Merrienboer (2004); and Chandler and Sweller (1991) all noted, that improperly designed instructional materials can increase cognitive load and diminish learning, so properly designed AR lesson can therefore increase learning. To investigate this further, it should be examined if AR can reduce cognitive load and if AR can increase learning gains when compared to traditional learning materials, such as text with image instructions.

From the spatial visualization abilities perspective, research reports that high spatial visualization learners prefer more complex visual representations, such as 2D

animations and 3D images, while learners with low spatial visualization abilities prefer simple visual representations, such as text or 2D images. However, in several studies, it was found that AR actually changes the human understanding of spatial information. This change of understanding often results in fuller conceptual understanding, perception of virtual objects as real and tangible, and reduction of cognitive load. These properties could make AR suitable for both low and high spatial visualization learners. To investigate these claims, it should be researched whether AR can supplement spatial visualization abilities of learners with low spatial abilities.

From a tactile sensory input perspective, AR differs from other instructional technologies because it can depict visual, tactile, and potentially auditory modalities. Reviewed literature reports mixed findings on using tactile modality during learning. Research studies that compared AR with other modes of instruction (physical models, paper instruction) reported that AR was very similar to physical models in performance and that it outperformed paper instruction. Studies that focused on the comparison of physical and virtual learning material reported that the use of physical modality did not significantly contribute to learning. Additionally, findings of the literature that explored haptic feedback during learning were mixed. Some researchers reported that haptics played a large role during learning while a smaller number of studies reported that it did not play any significant role during learning. In order to study these findings further, it should be examined whether the addition of tactile modality to AR instruction influences learning compared to traditional learning materials, such as printed text with images.

The primary purpose of this study is to examine (a) how AR performs as a learning tool when compared to other instructional treatments such as printed text with

images instruction; (b) if it can decrease cognitive load; and (c) supplement spatial visualization abilities of learners with low spatial abilities during learning.

Hypothesis

The following hypotheses will be tested in this study:

H1: There will be a significant difference in learning gains for the AR instructional treatment when compared to traditional text with images treatment.

H2: There will be a significant difference in NASA-TLX mean scores for the AR instructional treatment when compared to traditional text with images treatment. An AR astronomy lesson will have a lower mental workload when compared to text with images instruction.

H3: There will be no significant difference in learning gains between participants with low and high spatial visualization abilities in the AR astronomy treatment.

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CHAPTER THREE: METHODOLOGY

This chapter discusses the methodology that was used in this study. It contains the description of the participants, instruments, instructional content, tasks, and treatments used during the experiment, procedures, and research design.

Population and Sample

Research participants in this study were undergraduate students from a public university in southeastern United States. Initial study participants were students enrolled in multiple sections of 200- and 300-level psychology courses. Participants were recruited through a departmental psychology research pool via the SONA experiment management system. Students enrolled in all psychology courses had to take up to six credits of research and had to participate in several research studies to achieve this goal. This researcher offered three credits for participation in this study, since it required students to come to the experimental classroom and spend up to 75 minutes during the treatment.

Due to the low participant response rate towards the end of the data collection period, the original participant pool was modified and expanded. To expand the pool of participants, and through collaboration with Spanish department faculty, students who were enrolled in two 200-level Spanish courses were included into this study. Additionally, students were recruited via flyers posted around the university campus. Students from two additional recruitment methods were compensated monetarily for their participation while students recruited through the psychology pool were compensated via class credit.

Upon arriving to the experimental classroom, students were randomly assigned to one of two groups. The first group received an astronomy lesson about lunar phases that required study participants to use AR models and textual lesson to learn about lunar phases (Augmented Reality and Text Astronomy Treatment- ARTAT). The second group received the same astronomy lesson, but instead of AR models, participants used images and textual lesson to learn about lunar phases (Image and Text Astronomy Treatment -ITAT).

Instrumentation

Four instruments were used in this study: a demographic information form, a Paper Folding Test for assessment of spatial visualization abilities (Ekstrom et al., 1976), Lunar Phases Concept Inventory (LPCI) for pre-test and post-test assessment of lunar phases (Lindell, 2001), and NASA-TLX ("NASA TLX: Task Load Index", n.d.) for assessment of cognitive load experienced during the treatments.

Demographic Information Form

A short, five-item questionnaire was developed to collect basic demographic data from the study participants, including: college major, age, sex, ethnicity, and if the participants were the first in their family to go to college or not.

Paper Folding Test

The Paper Folding Test is a psychometric test used to measure human spatial visualization abilities (Mayer & Massa, 2003). This test "reflects processes of apprehending, encoding, and mentally manipulating spatial forms" (Carroll, 1993, p. 309), and according to Miyake et al. (2001), the test requires a complex sequence of

mental manipulations. The Paper Folding Test consists of two sections with 10 questions in each section. Time is measured and it is limited to three minutes per section. During the administration of the test, the participants were asked to imagine folding and unfolding pieces of paper. Each question explains how a particular piece of paper is folded and hole(s) punched through all the thickness of paper at that point. The folded piece of paper is then unfolded and the participants had to determine where the holes would appear once the paper was unfolded. Miyake et al. (2001), Kozhevnikov and Thorton (2006), and Kozhevnikov, Motes, and Hegarty (2007) successfully used the Paper Folding Test to measure spatial visualization abilities of the study participants. In this study, the Paper Folding Test was used to measure spatial visualization abilities of the study participants.

LPCI

LPCI is a multiple-choice inventory that is designed to help instructors measure student mental models and understanding of lunar phases (Lindell, 2001; Lindell & Olsen, 2002). This instrument was used as a primary tool for measurement of pre-test and post-test learning gains in both ARTAT and ITAT treatments. LPCI was adapted for this study to contain the 14 multiple-choice questions that were pertinent to the subject matter. This modification was made because the demographics information form that was distributed at the beginning of the study was already developed prior to adoption of LPCI.

NASA-TLX

NASA-TLX is a multi-dimensional subjective rating procedure that is used for mental workload assessment of human operators working with various human-machine systems such as simulations and laboratory tests ("NASA TLX: Task Load Index", n.d.). NASA-TLX consists of a multidimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales ("NASA TLX: Task Load Index", n.d.). These scales include Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort, and Frustration. In addition to these six scales, NASA-TLX also uses 15 pair-wise comparisons among the tasks to determine the degrees to which of each of the six factors contributes to the overall mental workload. However, these 15 pair-wise comparisons will not be used in this study because (a) they complicate the test itself; and (b) their impact will not significantly influence the mental workload assessment (Hill et al., 1992). Hart (2006) referred to this modified NASA-TLX as Raw TLX (RTLX) and this modification has gained a lot of popularity due to its simplicity. RTLX works by adding the scores of six ratings and averaging them. The resulting number (0-100) is an estimate of the overall mental workload.

Instrument Reliability

Paper Folding Test

Fleishman and Dusek (1971) researched the reliability of Ekstrom et al.'s (1976) Paper Folding Test and found it to be highly reliable (Pearson r = .84). However, Watson and Kimura (1991) noted that there is a strong trend for men to do better on the Paper Folding Test than women.

LPCI

Lindell (2001) reported the coefficient alpha for the 14-question LPCI pre-test to be 0.54 and for LPCI post-test to be 0.55. Both values indicate poor internal consistency and low instrument reliability.

NASA-TLX

NASA-TLX has been in use since the early 1980s and it is used to successfully measure mental workload. Hart (2006) pointed out that after 20 years of existence, NASA-TLX has achieved certain venerability, as it is being used as a benchmark against other tools in terms of efficacy of other measures, theories, and models. In terms of validity, NASA-TLX has been proven as a precise instrument that may come closest to tapping the essence of mental workload and "provide the most generally valid and sensitive indicator" (Hart & Staveland, 1988). In terms of reliability, Battiste and Bortolussi (as cited in Cao, Chintamani, Pandya, & Ellis, 2009) found a strong correlation between repeated measures. Additionally, Xiao, Wang, and Wang (2005) confirmed the reliability of NASA-TLX and suggested that this tool could be used to accurately assess mental workload.

Instructional Treatment

The lunar phases astronomy lesson used in this study was created using several printed and Internet sources (Bennett et al., 2010; Byrd, 2012; Dejoie & Truelove, 1995; Kids Know it Network, 1998; Teachers' Domain, 2005; Windows to the Universe team, 2010). After the lunar lesson was finished, two content experts who hold Ph.D. degrees in astrophysics collaborated briefly to validate the lesson content and redesign it for ARTAT and ITAT treatments. The final version of the lunar lesson consisted of textual

information, and depending on the treatment, 2D or 3D images that depict the earth's and moon's rotation around the sun and eight lunar phases (new moon, waxing crescent, first quarter, waxing gibbous, full moon, waning gibbous, third quarter, and waning crescent).

Augmented Reality and Text Astronomy Treatment (ARTAT)

This instructional treatment consisted of a printed textual lunar lesson (Appendix F) that had references to physical AR markers (fiducial markers). While reading about lunar phases, study participants were instructed to refer to the handheld fiducial markers (Figure 3.1) to learn more about the subject content. These handheld fiducial markers had 3D objects augmented on top of them (e.g., lunar phases) and they allowed the participants to physically manipulate them. This physical manipulation was almost the same as interaction with any other physical object, as it allowed the research participants to rotate and tilt the fiducial markers without losing sight of the augmented 3D content. The augmented 3D model would behave as if it was glued to the fiducial marker and it would rotate and tilt accordingly to the marker position (Figure 3.1). One thing to note is that 3D objects were visible to the participants only on the 24'' monitor and they were not visible with the naked eye.

Figure 3.1 Fiducial marker with augmented 3D model being held by one of the research participants



Description of treatment for ARTAT experimental group. At the beginning of the treatment, the participants were seated at a desk with a 24'' monitor. A Logitech Web camera was mounted on top of the monitor and connected to a quad core personal computer that was capable of processing standard definition 480p video signal and augmenting 3D models over fiducial markers. Upon explaining what they will be doing, study participants were trained (Appendix E) on how to use and interact with the fiducial markers.
Figure 3.2 Participant in ARTAT group, interacting with fiducial marker during the learning lesson



Training consisted of one fiducial marker with an augmented 3D object of the earth, the moon and the sun lined up (new moon phase). Research participants could see this augmentation on the 24'' monitor where the participants saw themselves manipulating a round piece of cardboard with a 3D model on top of it. The model behaved as the physical model would behave. For example, when the participants brought the fiducial marker closer to the camera, the model would get larger; when the participants moved the fiducial marker away from the camera, the 3D model would get smaller (Figure 3.1). The participants could also physically rotate the fiducial marker and the 3D models on the monitor would correspondingly behave to that rotation. They could also tilt the model approximately 160 degrees before the camera would lose track of the marker and the PC would stop augmenting the 3D object.

After finishing the training, study participants were given a lunar phases lesson with five accompanying fiducial markers. They were instructed to read the entire lecture, and interact with the fiducial markers when prompted to do so. They were also told to learn as much as possible and that there was no time limit for this lesson. After the participants completed the reading and interaction with the fiducial markers, they took the next test.

Images and Text Astronomy Treatment (ITAT)

This instructional treatment consisted of a printed textual lesson accompanied with appropriate 2D images of lunar phases (Appendix G). The textual lesson content was identical to the content used in the ARTAT treatment, but ITAT used 2D images instead of the 3D models of the lunar phases.

Description of treatment for ITAT control group. At the beginning of the ITAT treatment, study participants were seated at a desk and were given a lunar lesson that consisted of textual information and 2D images. The participants were instructed to read the entire lesson, learn as much as possible, pay special attention to the images as images convey lunar phases information explained in text, and understand that there is no time limit for the lesson. After the participants were finished reading the lesson, they submitted the learning materials and took the next test.

Procedure

The study was conducted in six stages during one hour. Participants signed up for the study through an online experiment management system and showed up at the experimental classroom at the assigned time. Upon entering the classroom, they were presented a deck of eight cards (four for ARTAT and four for the ITAT treatment) for each participant, and they were allowed to draw one card. If the research participant drew an "AR" labeled card, the participant was assigned to the ARTAT treatment, and if they drew a "Paper" labeled card, the participant was assigned to the ITAT treatment. ARTAT subjects were physically separated from the ITAT subjects by a mobile whiteboard or by improvised 15-foot long wall. Upon being seated, participants in both groups were given a demographic information form and an introductory letter, which explained the purpose of this study. This stage lasted approximately five minutes.

In the second stage, the Paper Folding Test was administered to both groups to determine the spatial visualization abilities of each research participant. Participants were told to read the instructional page of the instrument, and after they completed this task, they were instructed to wait for further instructions and not to turn to the second page of the instrument. After the participants completed the sample problem on the instructions page of the Paper Folding Test, they were instructed that they had three minutes to complete each section of the Paper Folding Test and not to turn any pages unless instructed to do so. The tests were collected after the participants completed both sections of the Paper Folding Test. The second stage lasted approximately 10 minutes.

In the third stage of this experiment, the participants in both groups were given an astronomy pre-test (LPCI). The astronomy pre-test assessed for astronomy knowledge that most college students should have acquired during their K-12 education. This test consisted of 14 multiple-choice questions and most participants completed this test in less than 10 minutes. Participants were instructed to place their answers on a bubble sheet and that this test was not timed.

In the fourth stage, participants were administered either an ARTAT or ITAT instructional treatment. It was assumed that few students had interacted with AR models in the past, so for the subjects in the ARTAT treatment, a brief training session helped to eliminate misconceptions and improper use of the fiducial markers. The training session consisted of one fiducial marker that depicted the earth, the moon, the sun and an

instruction sheet that (a) showed the research subject how to hold the fiducial marker and (b) instructed the subject to align the fiducial maker, as shown in Figure 3.1. After finishing the training session that lasted approximately two or three minutes, subjects were given an ARTAT instructional treatment that consisted of a textual lesson with references to fiducial markers. The ITAT subjects did not require any training and were given their treatment right after they completed the LPCI pre-test. Participants in this stage spent an average of 11 minutes interacting with the learning material.

In the fifth stage, the subjects in both groups were given a NASA-TLX test to measure their mental effort that they experienced during the treatment. Participants were instructed to read the instructions for the NASA-TLX, and place an "X" in between the scales. It took approximately five minutes to complete this stage of this study.

In the sixth stage, the participants filled out the lunar phases astronomy post-test (LPCI). Instructions from step two were repeated and subjects were told that this was the last test in the study. This stage of the experiment lasted approximately 10 minutes.





After the sixth stage, participants were given a debriefing form and were told to keep it in case they have to write a class assignment about their experience or if they needed to contact the principal investigator. Participants were then thanked for their participation and were given research participation credit in online experiment management system.

Research Design

This study used a randomized groups pre-test-post-test experimental design (Table 3.1). This type of design allows for the manipulation of blocking and independent variables, including the participant's spatial abilities and prior astronomy knowledge. Dependent variables in this study include the cognitive load and post astronomy knowledge. After the sixth stage, participants were given a debriefing form and were told to keep it in case they have to write a class assignment about their experience or if they needed to contact the principal investigator. Participants were then thanked for their participation and were given research participation credit in online experiment management system.

Tal	ble	3.1	Research	h I	Design
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Measurement	Variable	Instrument	Analysis
Spatial	Blocking	Paper	This variable was used to measure
visualization		Folding	spatial visualization abilities of
abilities		Test	learners.

Research Design

Table 3.1 (Continued)

Prior astronomy knowledge	Independent	Astronomy pre-test (LPCI)	This variable was used to benchmark participant's prior knowledge of astronomy concepts and to compare it to the knowledge gains after the instructional treatments.
Cognitive load	Dependent	NASA- TLX	This measurement was used to determine which instructional treatment caused the most cognitive load.
Post treatment astronomy knowledge	Dependent	Astronomy post-test (LPCI)	This variable was used to compare knowledge gains between the ARTAT and ITAT groups.

Experimental Validity

abilities.

Internal validity. One potential threat to the internal validity of this study is the sampling bias and characteristics of the participants. Having a true random sample from the entire student population of the university is not feasible therefore a selected sample of the student population may not be an accurate representation of the larger population. This may also cause a systematic bias where the difference between the sampled populations differs from the theoretical results of the entire population. Additionally, instrumentation will not be an issue to the internal validity the instruments that are used are reliable in measuring knowledge gains, mental workload, and spatial

External validity. No threats to the external validity were found in this research design.

Data Analysis Procedures

This study used quantitative data analysis methods to accept or reject the research hypotheses. Quantitative data consisted of the astronomy pre-test and post-test (LPCI) scores, Paper Folding Test scores and the NASA-TLX mental workload scores. Descriptive statistics and the intercorrelation of outcome measures were computed and ttests were be used for the hypothesis testing.

Summary of Methodology

Research participants in this study were undergraduate students from a public university in eastern Kentucky. Initial participants included students enrolled in psychology courses and were a part of departmental research pool. The pool of participants was later expanded to include students from the language department and university students who were recruited through the use of advertisement flyers.

Instruments used in this study included the following: a demographic information form, a Paper Folding Test, which was used to assess individual spatial abilities, a lunar phase pre-test and post-test (LPCI), and NASA-TLX, which was used to assess mental workload for each treatment.

Two treatments were used in this study: ARTAT and ITAT. ARTAT was an experimental treatment where the participants were given a lesson on lunar phases that included augmented 3D objects as supporting learning materials. ITAT was a control group in which the participants were given the same astronomy lesson as the students in ARTAT treatment, but instead of augmented 3D objects, participants observed 2D images.

The process of data collection lasted approximately one hour. Upon entering the experimental classroom, research participants drew a card and were assigned to one of the two treatments. Upon seating, they were given demographic information form and the rest of the instruments in the following order: a Paper Folding Test, lunar phases pre-test (LPCI), instructional treatment, NASA-TLX, and an astronomy post-test (LPCI) (Figure 3.2). After completing the astronomy post-test, the participants were given a debriefing form, thanked for their participation, and given credit for research participation.

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CHAPTER FOUR: RESULTS

The findings that were revealed during the data analysis can be divided into three sections: Demographics Data, Descriptive Statistics, and Primary Data Analysis. The Demographics Data and Descriptive Statistics sections of this chapter describe the main features of demographic data while the Primary data Analysis section reports the results of inferential statistics analysis.

Demographics Data

Research participants in this study were recruited from the undergraduate student population at a public university in the southeastern United States. Specifically, the majority of the participants were recruited from the Psychology department research pool and consisted of students enrolled in 200- and 300-level undergraduate psychology courses. The breakdown of research participants by gender, age, and academic areas for ARTAT and ITAT groups are reported in Table 4.1.

Due to the low participant response rate towards the end of the data collection period, the pool of research participants expanded to include students from two 200-level undergraduate Spanish courses and students from the general university population, who were recruited via flyers posted around the university campus. Students who were recruited through the Psychology department were compensated with class credit while students who were recruited from Spanish courses and through flyers were compensated monetarily. This study concluded with a total of 182 participants (n=89 for ARTAT group, n=93 for ITAT group).

Upon entering the experimental classroom, the participants were randomly assigned to an experimental (ARTAT) or control (ITAT) group and were seated at either

a computer or at an empty desk. Each participant was given the following: (a) test of spatial abilities (Paper Folding Test); (b) astronomy pre-test (LPCI); (c) learning treatment (astronomy lesson about lunar phases); (d) test of cognitive load (NASA-TLX); and (e) astronomy post-test (LPCI). Data collection time for each student ranged between 35 and 50 minutes.

			ARTAT		T	All Students
Parameter		n	Percent	n	Percent	Ν
Gender	Male	40	45%	45	48%	85
	Female	49	55%	48	52%	97
Age	18-20	47	53%	54	58%	101
	21-25	30	34%	33	35%	63
	26+	12	13%	6	6%	18
Academic	Arts & Sciences	46	52%	40	43%	86
Areas	Business & Technology	11	12%	10	11%	21
	Health Sciences	16	18%	21	22%	37
	Other Academic Areas	16	18%	22	24%	30
Total Stud	ents	89	49%	93	51%	182

Table 4.1 Research Participants by Gender, Age, and Academic Area

Note. ARTAT abbreviation represents the Augmented Reality and Text Astronomy Treatment group, while ITAT represents the Images and Text Astronomy Treatment group.

Descriptive Statistics

Before delving into statistical analysis, reliability of the LPCI instrument needed to be measured. Lindell (2001) reported the coefficient alpha for the 14-question LPCI pre-test to be 0.54 and for LPCI post-test to be 0.55. For this study, the coefficient alpha value for the 14-question LPCI pre-test (n=182) was .38, and the coefficient alpha value for the 14-question LPCI post-test (n=181) was .50.

The means and standard deviations for the Lunar Phases Concept Inventory

(LPCI) pre-test, LPCI post-test, mean difference scores for the two instructional

treatment groups, participant gender, age and academic areas are reported in Table 4.2.

The LPCI was designed to help instructors measure student mental models and understanding of lunar phases (Lindell, 2001). This instrument was used to measure knowledge gains during pre-test and post-test treatment. The LPCI consists of 14 multiple-choice questions. Based on these 14 questions, mean and standard deviations values for the LPCI pre-test, the post-test, and the difference scores were calculated. The two instructional treatments were the Augmented Reality and Text Astronomy Treatment (ARTAT) and the Images and Text Astronomy Treatment (ITAT). The ARTAT participants were given a textual lesson about lunar phases with AR models to supplement the textual information, while the ITAT group was given integrated text with images.

Table 4.2 Mean and Standard Deviation scores for Pre-test, Post-test, and DifferenceScores, by Treatment, Gender, Age, and Academic Area

	LPCI	Pre-test	LPCI	Post-tes	t Differ	ence
Parameter	М	SD	М	SD	М	SD
Treatment						
ARTAT	5.17	1.93	8.28	2.07	3.11	2.14
ITAT	4.95	2.17	7.95	2.11	3.00	2.45
Gender						
Male	5.52	2.22	8.41	2.2	2.89	2.35
Female	4.64	1.82	7.85	1.97	3.20	2.26
Age						
18-20	4.73	1.97	7.95	2.16	3.21	2.24
21-25	5.47	2.17	8.32	1.97	2.85	2.39
26+	5.28	1.90	8.22	2.21	2.94	2.33
Academic Areas						
Arts & Sciences	5.38	2.21	8.50	1.74	3.12	2.29
Business & Technology	4.86	1.74	8.48	2.18	3.62	1.85
Health Sciences	4.22	1.78	7.14	2.08	2.92	2.49
Other Academic Areas	5.24	1.92	7.97	2.09	2.74	2.37

LPCI pre-test means score for the ARTAT group was 5.17 while the means score for the ITAT group was 4.95. The means values for gender were 5.52 for males and 4.64 for females. The means values for the three age groups were as follows: M = 4.73 for 18-21 year olds, M = 5.47 for 21-25 year olds, and M = 5.28 for 26 year olds and older. Lastly, the means breakdown by academic area was as follows: M = 5.38 for Arts and Sciences, M = 4.86 for Business and Technology, M = 4.22 for Health Sciences, and M = 5.24 for Other Academic Areas.

The LPCI post-test means score for the ARTAT group was 8.28 while the means score for the ITAT group was 7.95. The means values for the gender were 8.41 for males and 7.85 for females. The means values for the three age groups were as follows: M = 7.95 for 18-21 year olds, M = 8.32 for 21-25 year olds, and M = 8.22 for participants that were 26 year old and older. Finally, the means breakdown by academic area for the LPCI post-test was as follows: M = 8.50 for Arts and Sciences, M = 8.48 for Business and Technology, M = 7.14 for Health Sciences and M = 7.97 for Other Academic Areas.

Difference scores were calculated by subtracting the LPCI pre-test scores from the LPCI post-test scores for each participant. The means scores for the ARTAT group were 3.11 while the means scores for the ITAT group were 3.0. The means values for gender were 2.89 for males and 3.2 for females. The means values for the three age groups were as follows: M = 3.21 for 18-21 year olds, M = 2.85 for 21-25 year olds, and M = 2.94 for 26 year olds and older. And lastly, the means breakdown by academic area was as follows: M = 2.12 for Arts and Sciences, M = 3.62 for Business and Technology, M = 2.92 for Health Sciences and M = 2.74 for Other Academic Areas.

This study used a subjective scale test developed by NASA to measure participants' cognitive load after completing the lunar phases lesson in both treatments (ARTAT and ITAT). NASA-TLX consists of a multidimensional rating procedure that derives an overall cognitive load score. The resulting number (0-100) provides an estimate of overall cognitive load and it was used in this study to derive statistical values (Table 4.3).

The cognitive load means scores for the ARTAT group was 30.1, while the mean score for the ITAT group was 36.9. The means scores for gender were 34.05 for males and 33.2 for females. The means values for the three age groups were as follows: M = 32.3 for 18-21 year olds, M = 35 for 21-25 year olds, and M = 35.7 for 26 year olds and older. The means breakdown by academic areas was as follows: M = 33.61 for Arts and Sciences, M = 31.8 for Business and Technology, M = 32.86 for Health Sciences and M = 35.39 for Other Academic Areas.

	Cogniti	ive Load	Spatia	l Abilities
Parameter	М	SD	М	SD
Treatment				
ARTAT	30.10	14.80	11.08	3.23
ITAT	36.90	14.32	11.54	3.31
Gender				
Male	34.05	15.76	11.64	3.34
Female	33.20	14.10	11.03	3.21
Age				
18-20	32.30	15.24	11.23	3.28
21-25	35.00	14.41	11.45	3.09
26+	35.70	14.87	11.22	3.99
Academic Areas				
Arts & Sciences	33.61	14.79	11.76	3.14
Business & Technology	31.80	15.81	11.05	3.10
Health Sciences	32.86	14.70	10.32	3.37
Other Academic Areas	35.39	15.22	11.42	3.47

by Treatment, Gender, Age, and Academic Area

The Paper Folding Test is a psychometric test that is used to measure human spatial visualization abilities (Mayer & Masa, 2003). This test measures complex sequences of apprehending, encoding, and mentally manipulating spatial forms (Caroll, 1993, p. 309). The test consists of 20 questions and the participants were required to complete as many questions as they could in six minutes. The purpose for administering this test was to measure if AR can aid learners with low spatial abilities to learn spatial content as well as learners with high spatial abilities. Similar to NASA-TLX, this test also yields a number (0-20) that was used to perform statistical analysis.

After completing the data analysis, it was determined that the mean scores for ARTAT group was 11.08 and the mean scores for the ITAT group was 11.54. The means values for gender were 11.64 for males and 11.03 for females. The means values for the three age groups were as follows: M = 11.23 for 18-21 year olds, M = 11.45 for 21-25

year olds, and M = 11.22 for 26 year olds and older. Lastly, the means breakdown by academic area was as follows: M = 11.76 for Arts and Sciences, M = 11.05 for Business and Technology, M = 10.32 for Health Sciences and M = 11.42 for Other Academic Areas.

Primary Data Analysis

Hypothesis Testing

In this section, the primary hypothesis of this study will be tested using both the two-sample independent t-test and one-way ANOVA.

Hypothesis #1 states that there will be a significant difference in learning gains for the AR instructional treatment when compared to traditional text with images treatment.

This hypothesis was tested by calculating the difference score between the LPCI pre-test and post-test scores (Difference Score column in Table 4.4). The difference score was calculated by subtracting the LPCI pre-test values from the LPCI post-test values and by performing the t-test on newly obtained values. Before these results are discussed, we will first discuss the statistical analysis of the LPCI pre-test scores, to determine if the entry knowledge about the lunar phases for both groups was equal. Statistical analysis of these scores included the t-test and one-way ANOVA.

To test if the entry knowledge about the lunar phases was equal in both the ARTAT and ITAT groups (LPCI pre-test), an independent samples t-test was performed to compare the pre-test means scores between the two treatment groups. The resulting t-test score indicated that there was no significant difference between the pre-test means for the two treatment groups t(180) = .72, p> .05. It can therefore be concluded with a

95percent confidence level that there were no significant differences in performance in between the ARTAT group and ITAT group on the astronomy pre-test (LPCI).

Table 4.4 T-test and One-Way ANOVA Scores for Scores Difference by Treatment,

	Scores D	oifference	
Parameter	t / F	DF	Р
Treatment			
ARTAT	t = .32	180	.74
ITAT			
Gender			
Male	t = .881	180	.38
Female			
Age			
18-20	F = .51	2, 179	.59
21-25			
26+			
Academic Areas			
Arts & Sciences	F = .72	3, 178	.541
Business & Technology			
Health Sciences			
Other Academic Areas			

Gender, Age, and Academic Area

Considering that there was no significant statistical difference between the pretest means scores for the two treatment groups, secondary data analysis was conducted to determine if there were any effects for gender, age, and academic area. A statistically significant difference in means scores for the pre-test was found between males and females t(180) = 2.89, p < .01. In addition to gender differences, significant differences were found between four academic areas F(3, 178) = 3.04, p < .05. The differences were found between the Arts and Sciences and Health Sciences groups. Based on the results of the t-test and ANOVA, differences between participants age were not statistically significant. To test Hypothesis #1, the difference scores between the LPCI pre-test and posttest scores (Difference Scores column in Table 4.4) were calculated and a t-test analysis between the ARTAT and ITAT treatment groups were conducted to see if there was any change in learning between the groups. The results of the statistical analysis yielded no significant difference between the ARTAT and ITAT groups (Table 4.4). Based on these findings, the Hypothesis # 1 can be rejected with 95 percent confidence. It can be concluded that students using Augmented Reality during instruction performed no better than students who used traditional text with images learning materials.

A secondary data analysis was performed to find any potential differences between participants' gender, age, and academic area and found no difference between the groups.

Hypothesis #2 asserts that *there will be a significant difference in NASA-TLX means scores for the AR instructional treatment when compared to traditional text with images treatment.* It is assumed that the AR astronomy lesson will create a lower mental workload when compared to text with images instruction.

To test this hypothesis, the cognitive load means scores between the two treatment groups (ARTAT and ITAT) were compared. An independent samples t-test was also used to analyze the means scores, and a significant statistical difference was observed (Table 4.5). Based on obtained data, it can be concluded with 95 percent confidence that the cognitive load for the students using Augmented Reality during instruction was significantly lower than the cognitive load experienced by students who used traditional text with images learning materials (Table 4.5).

A secondary data analysis was performed to compare the means scores for the cognitive load, gender, age, and academic areas. No significant statistical differences were found.

Table 4.5 T-test and One-Way ANOVA Scores for Cognitive Load by Treatment, Gender,Age, and Academic Area

	Cognitive	e Load	
Parameter	t/ F	DF	Р
Treatment			
ARTAT	t = -3.17	180	.002
ITAT			
Gender			
Male	t = .36	180	.71
Female			
Age			
18-20	F = .85	2, 179	.42
21-25			
26+			
Academic Areas			
Arts & Sciences	F = .31	3, 178	.81
Business & Technology			
Health Sciences			
Other Academic Areas			

The final hypothesis tested in this study pertained to participants' spatial abilities within the ARTAT group and whether spatial abilities influenced learning outcomes (scores difference). Hypothesis #3 asserts that *there will be no significant difference in learning gains between participants with low and high spatial visualization abilities in the AR astronomy treatment*.

To test Hypothesis #3, the spatial ability scores within the ARTAT group needed to be divided into high and low spatial scores. The first tertile (0-6) of Paper Folding Test scores in ARTAT group was chosen to represent the learners with low spatial scores, while the third tertile (14-20) of the Paper Folding Test scores represented the learners with high spatial scores. The scores (n = 8 for the learners with low spatial abilities, and n = 21 for the learners with high spatial abilities) were then compared with the corresponding difference scores for the ARTAT group via a t-test. The resulting t-test analysis produced no significant difference t(87) = .40, p > .05. The lack of statistical significance in difference scores change between the participants with high and low spatial abilities in ARTAT group indicates that the Hypothesis #3 can be accepted.

Summary of Data Analysis

After comparing the means of the LPCI difference scores, no statistically significant difference was found for learning gains between the ARTAT and ITAT groups. Although the mean scores for the ARTAT group were higher, the results were not statistically significant, so Hypothesis #1 can be rejected.

A secondary data analysis was performed to determine if there was any difference between the ARTAT and ITAT groups between age, gender, and academic areas for the LPCI pre-test, post-test, and difference scores. A statistically significant difference for the LPCI pre-test means scores was found between males and females and between the four academic areas. The means differences in academic areas were found between the Arts and Sciences and Health Sciences groups.

The second hypothesis that was tested was whether there would be a significant difference in the NASA-TLX means scores for the AR astronomy lesson when compared to the more traditional instructional treatment, such as text and images lesson. The statistical analysis of the NASA-TLX scores (cognitive load scores) returned significant statistical differences between the ARTAT and ITAT groups (Table 4.5), so Hypothesis #2 can be accepted. It was observed that the students in the ARTAT group experienced

lower cognitive load than the students in the ITAT group. The secondary data analysis returned no statistically significant difference for gender, age, and academic areas between the two groups.

The last hypothesis (Hypothesis #3) tested in this study asserted that there would be no significant difference in learning gains between the participants with low and high spatial visualization abilities in the AR astronomy lesson (ARTAT). The low spatial scores (0-6 on Paper Folding Test) and high spatial scores (14-20 on Paper Folding Test) in ARTAT group were compared with participant learning performance. No statistically significant differences were found and Hypothesis #3 could not be rejected.

The results of the hypothesis testing will be discussed in Chapter 5.

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CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

The use of augmented reality (AR) for educational applications is still in infancy (Kerawalla et al.; 2006). In order to fully comprehend and understand the potential of AR as a learning technology, further research in the area of effectiveness of AR is essential. Especially important is the research that delves into learning with AR and the best way to utilize this unique technological concept. Therefore, the purpose of this study was (a) to examine how learning takes place with AR, and how AR compares with other, more established, instructional technologies, such as printed text with images when it comes to learning; (b) to examine the effects AR has on cognitive load, and the implications from the Cognitive Load Theory perspective; and (c) to examine the effect that AR has on learners' spatial abilities.

The theoretical framework that was used in this study was guided by the principles as outlined by the Cognitive Load Theory. This theory provides guidelines that assist in the design and presentation of information by taking the human cognitive structure into consideration. Instructional materials designed with the Cognitive Load Theory framework tend to (a) decrease the extraneous cognitive load, which is often caused by the improperly designed instructional materials; (b) decrease the intrinsic cognitive load, which is often caused by the difficulty of the learning content; and (c) increase the germane cognitive load, which is associated with knowledge (schema) construction.

AR may potentially reduce extraneous and intrinsic cognitive load by representing visual information, which is usually in the form of 3D images, by providing full spatial representations that are simple to comprehend. Unlike 2D visual information that must be

integrated mentally into 3D information to closely match our model of the 3D model of the world, AR provides already-integrated information. This property can relieve the working memory load and allow learners to direct additional memory resources to germane cognitive load processing.

From the perspective of spatial abilities, literature reports that AR (3D) and similar modes of information representation, such as images (2D), VR, animation, and video, can influence spatial abilities (Cohen, 2005; Yang et al., 2003; Kozhevnikov, Motes, & Hegarty, 2007; Huk, Steinke, & Floto, 2003). The benefit of this influence is that the processing requirement of spatial information may be reduced, thus relieving the load on working memory. This may be especially beneficial for learners with low spatial abilities as their spatial visualization abilities can be expanded (Kozhevnikov, Motes, & Hegarty, 2007).

Discussion by Hypothesis

The following discussion is based on the three hypotheses for this study.

Comparison of Learning Gains Between ARTAT and ITAT Groups

Hypothesis #1 states that there will be a significant difference in learning gains for the AR instructional treatment when compared to traditional text with images treatment.

The two treatment groups were tested with an astronomy pre-test and post-test (LPCI), and the means of the score difference were statistically analyzed to see if there was any difference between them. Statistical analysis indicated that there was no statistical significance between the ARTAT and ITAT groups. The mean score for the ARTAT group was 3.11 while the mean score for the ITAT group was 3.0.

There are several potential reasons for not obtaining the statistical significance for Hypothesis #1. One reason could be attributed to the number of questions in LPCI that focused on spatial phenomena. The version of LPCI used in this study contained 14 multiple-choice questions. Of the 14 questions, only six questions assessed knowledge that could have been categorized as spatial and that could have been obtained easily during the learning treatment. The remaining questions assessed the factual knowledge that required rote memorization, for which there was no time during the brief learning session. Statistical analysis was performed on six selected spatial questions, but it did not yield a statistically significant difference. However, the means for the ARTAT group were marginally higher (M=1.96) than the means for the ITAT group (M=1.78). This was a small difference, but it is an indicator that if more questions had focused on the assessment of spatial knowledge, a statistical significance could in fact be measured.

The second reason for not obtaining statistical significance could be attributed to the low reliability and internal consistency of the pre-test/post-test instrument (LPCI). George and Mallery (2007) suggested that alpha values for the scale-type instruments with high internal consistency are between 0.7 and 0.8, and the alpha values for the instruments with low internal consistency are between 0.5 and 0.6. Internal consistency values calculated in this study were 0.34 for pre-test, and 0.50 for post-test. Low instrument reliability could have been one of the reasons that contributed to not finding statistically significant differences in learning between the ARTAT and ITAT groups.

The third reason for not obtaining statistical significance could have been assigned to the interest of the study participants. Most participants took part in this study for class credit, and they were not interested in the research outcomes. It was only later in

the semester that additional paid participants were recruited. A significant attitude change was observed between the students who participated in this study for class credit and students who were completing it for financial incentive. Paid students appeared to be more interested and seemed to feel obligated to perform well because they were receiving financial reimbursement, where as the students who participated in the study for class credit appeared less interested.

The forth reason for not obtaining statistical significance for Hypothesis #1 was the duration of the learning treatment. The majority of students completed the learning exercise in less than 11 minutes. It was also evident that the students in the ITAT treatment took less time than the students in the ARTAT treatment. This is not enough time to teach a rather complicated concept such as lunar phases, as most lessons on this subject take one class period and supplemented with assigned homework. The time it took for students to participate during the experiment was not sufficient for students to fully grasp the concept of lunar phases.

And lastly, it is probable that the LPCI instrument correctly measured the learning gains in-between the two groups (ARTAT and ITAT), and that the results of statistical analysis performed for Hypothesis #1 are correct. Perhaps there are no real learning differences between the ARTAT and ITAT groups.

Comparison of Cognitive Load Scores Between ARTAT and ITAT Groups

Hypothesis #2 asserted that *there will be a significant difference in the NASA-TLX mean scores for the AR instructional treatment when compared to traditional text with images treatment.* Both the ARTAT and ITAT groups were given an instrument that subjectively measured perceived cognitive load (NASA-TLX) during the learning exercise. Statistical analysis indicated that there was a statistical significance between the two groups. The means score for the ARTAT group was 30.1, while the means score for the ITAT group was 36.9.

It is important to point out the magnitude of the score difference between the cognitive load scores of two groups. The ARTAT group experienced 15% (6.8 points) reduction in cognitive load when compared to the ITAT group. This difference can translate into increased learning capacity and better information processing during learning. This is significant because learners can better process and comprehend learning lesson they are presented with.

These results are consistent with the studies by Haniff and Baber (2003), Tang et al. (2003), Klatzky et al. (2008), and Wang and Dunston (2006), who also found that AR could lower cognitive load in a variety of situations and with various interfaces.

This reduction of cognitive load can be attributed to the ability of AR to offer a more complete representation of a spatial or any other visual concept (Haniff & Baber, 2006). For example, during the lunar lesson, study participants manipulated the 3D image or lunar phases with their hands. If they wanted to rotate the image 360 degrees, they only had rotate the fiducial marker in their hands and the 3D image would rotate correspondingly on the computer monitor. There was no need to imagine the rotation; all they had to do to get a complete representation was use their hands. However, the students in ITAT group had to integrate 2D images mentally to be able to rotate them.

Students in the ITAT group could rotate the paper with the printed image, but such action is generally deemed to be unnatural and unusual.

Although not measured in this study, tactile interface of fiducial markers could have contributed to the overall user experience, better material comprehension, and lower cognitive load. Tactile sensory modality is processed in a visuo-spatial sketchpad, and it is a component of working memory (Baddeley, 2007). Mousavi et al. (1995) also noted that adding tactile sense to learning could increase learning and reduce cognitive load. Following this reasoning, one could reduce the cognitive load and promote deeper learning by using tactile sensory information in addition to the visual and/or auditory sensory information during the lesson.

It is important to mention that the AR treatment was not designed according to the principles of the Cognitive Load Theory. The 3D images that were part of the lunar phases lesson, were not integrated with the text. During the AR treatment, participants were required to read the textual lunar phases lesson, and when prompted, look away from the textual content, pick up the fiducial marker, and interact with the 3D content. This type of instructional design requires the learner to hold textual information in working memory, and integrate it with the visual information at later times. This is also called the split-attention effect. It generally increases mental workload and it is detrimental to learning (Sweller, Ayers, & Kalyuga, 2011). The reasons for not integrating the visual and textual information for the ARTAT group were caused by the technical limitations of AR. The ITAT group did not experience such design limitations, and the 2D images in the ITAT group were integrated with the textual information. Faced

with this obvious design flaw, the ARTAT group still experienced lower cognitive load than the ITAT group.

Comparison of Spatial Ability Scores Between ARTAT and ITAT Groups

Hypothesis #3 asserted that there would be no significant difference in learning gains between the participants with the low and high spatial visualization abilities in the AR astronomy treatment.

The two treatment groups were given a Paper Folding Test to measure participants' spatial abilities and to later compare them against performance change, which was measured by the LPCI. Paper Folding Test scores within the ARTAT group were divided into high and low spatial scores. The first tertile (0-6) of the Paper Folding Test scores was chosen to represent the learners with low spatial scores, while the third tertile (14-20) of the Paper Folding Test scores, represented the learners with high spatial scores. These scores were then compared with the corresponding difference scores for the ARTAT group with a t-test. It was concluded that there was no statistical significance, as learners with low spatial abilities performed the same as the learners with high spatial abilities. Therefore, Hypothesis #3 was accepted.

Research related to spatial abilities is diverse, but the general consensus is that learners with low spatial abilities prefer simple modes of information presentation, such as 2D (Huk et al., 2003; Kozhevnikov et al., 2007), while the learners with high spatial abilities prefer more complex modes for information presentation, such as 3D and animation (Yang et al., 2003; Cohen, 2005; Kozhevnikov, Motes, & Hegarty, 2007). For the purpose of comparing learners with low and high spatial abilities, and measuring the learning gains between the two groups, Wang, Chang, and Li (2007) did not find any

significant significance. Dunser et al. (2006) also failed to measure gains in spatial abilities during a training lesson, and argued that traditional spatial ability tools do not measure all of the skills that are used when learners interface with 3D content and space.

It is difficult to determine if the Paper Folding Test measured the type of spatial abilities that were beneficial when learning spatial problems. Even though Hypothesis #3 was accepted, and no significant difference was found, the number of participants with low and high spatial scores was too small to be able to draw meaningful statistical conclusions.

Based on the reviewed literature, it may be worthwhile to continue exploring whether AR can aid learners with low spatial abilities when they interact with content that is rich in spatial information. This study failed to reject Hypothesis #3, but it was a moot assumption due to the low number of participants in two groups. Perhaps future studies should duplicate this study with an instrument that accurately measures knowledge gains, and compare those scores with the spatial ability scores to see if AR can indeed aid learners with low spatial abilities.

Limitations and Suggestions for Future Research

Study Limitations

This study suffered from several limitations. The first limitation was the low number of questions (LPCI) that measured spatial knowledge obtained during the learning exercise. Spatial knowledge is the type of knowledge that learners acquired while manipulating fiducial markers in the ARTAT group, or mentally rotating and integrating 2D images in the ITAT group. Only six questions on the LPCI measured this type of knowledge. For future research, an instrument that focuses more on the

measurement of spatial knowledge should be used. Another solution would be to modify the existing 14-question LPCI, and add several questions that measure skills acquired while interfacing with the AR systems. The last recommendation would be to adopt an alternative approach to assessing students' learning gains. The concept of lunar phases is rather complex, and a 14-question, multiple-choice test may not be the best method for assessment of learning. Perhaps an essay or an oral exam would better gauge student's knowledge of lunar phases.

The second limitation was the LPCI instrument that was used to measure the learning gains between the ARTAT and ITAT groups. The 14-question multiple-choice instrument had a low reliability, and this could have caused not to find statistically significant difference between the groups. In the future research, LPCI should be modified to increase the instrument reliability, or an entirely new instrument should be used.

The third notable limitation was the length of instruction. It was observed that participants in the ARTAT group completed the lunar phases lesson in approximately 11 minutes, while the approximate completion time for the participant in the ITAT group was 8 minutes. Unfortunately, the research design of this study was such that it did not allow for longer instruction time due to the large number of students required, as well as the large number of instruments used. Based on the experience acquired during the data collection process, it is suggested that the concept of lunar phases should be taught longer than the approximate reported time for the ARTAT and ITAT groups. In the future, the design of the lunar phases lesson should be such that it requires a minimum of 45 minutes

of student engagement with the learning content. The lesson should include exercises, and even homework, so that students would fully grasp the concept of lunar phases.

The fourth limitation of this study was the study participants themselves. A large majority of the participants were recruited through the psychology pool, and they took part in the study for class credit. Based on researcher observations, many students appeared uninterested, and seemed like they wanted to finish the study as quickly as possible. This happened for both ARTAT and ITAT groups, so this behavior could not have contributed to rejecting the Hypothesis #1. For the future, this study should be duplicated with subjects who are more invested in the content matter and the outcome results.

The last limitation in this study was the AR technology. This study utilized LCD monitor and a webcam to generate reality that is augmented with 3D models of lunar phases. Participants in the ARTAT treatment were required to manipulate fiducial markers and observe the augmentation of 3D models live on a LCD monitor. This setup may have caused orientation displacement and reduced immersion. Previous studies have shown for these factors to increase cognitive load and task completion time (Chen et al., 2009; Wang & Dunston, 2006). An ideal AR system for this study could be constructed with a see-through HMD, and AR software that is able to account for marker occlusion, and offer flawless tracking. Unfortunately, at the time of this research study, see-through HMD's are rare, exorbitantly expensive, and were not available for this study. The technology utilized in this study (LCD monitor and webcam) was adequate, and it can be viewed as a stepping-stone towards a more technologically advanced AR system.

Implications for Future Research

This study examined the impacts of AR on student learning, cognitive load, and spatial abilities. Although there were no significant differences in learning gains, significant differences were observed for cognitive load. The ARTAT group experienced lower cognitive load when compared to the ITAT group. For future research, it would be beneficial to repeat this study with (a) a modified LPCI instrument that would include more questions that relate to measurement of spatial knowledge; and (b) adopt another means of assessment, such as essays or oral exams, to measure knowledge acquisition. This change should accurately capture the learning difference between AR, and the traditional mode of instruction, such as the one used in this study (text with images). Also, it would be interesting to compare AR with other types of instructional technologies, such as instructional video, animation, and physical objects.

Another venue of further research would be to replicate this study with a different content lesson. There are a myriad of concepts in the science, technology, engineering, and mathematics (STEM) fields that could be adapted to lessons that utilize AR. The lunar phases lesson used in this study was suitable and it worked well, but due to extensive terminology and the time required for its completion, it may be easier to identify another lesson rich with spatial knowledge that is suitable for AR treatment, and replicate this study with that lesson.

Tactile is one dimension that was examined in Chapter 2, but it was not part of the research design in this study. Research on the effects of learning content that requires tactile manipulation is mixed, but from the viewpoint of the Cognitive Load Theory, adding another sense to learning could improve learning. Physical interaction with the

fiducial markers most likely influences learning to some degree, and it would be beneficial to determine how learning is influenced by the sense of touch, and how can AR facilitate this process.

Summary

This study found no significant difference in learning gains between the Augmented Reality and Text Astronomy Treatment group, and Images and Text Astronomy Treatment group (Hypothesis #1). This study also found statistically significant differences for cognitive load scores, as the group that received the experimental treatment that included Augmented Reality (ARTAT) experienced lower cognitive load. Lastly, no differences were found between participants with high and low spatial abilities within the ARTAT group, and Hypothesis #3 was accepted. However, due to the low number of subjects in this analysis, the results of this analysis are debatable.

Given the differences in cognitive load for the two treatments (ARTAT and ITAT), future studies that (a) explore the viability of AR as an instructional technology, and (b) focus on finding differences in learning between AR and more traditional learning technologies such as text with images, video, and animation, should take this into consideration.

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APPENDIX A: SURVEY OF RESEARCH STUDIES IN AUGMENTED REALITY

<i>Tuble III Research shalles that Joeus on augmented really</i>	Al Research studies that focus	on augmented reality
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Author / Study	Theoretical grounding	Subjects	Purpose/Hypothesis	Methods / Treatments	Results
Billinghurst and Kato (2002)				Study that compared AR to traditional AV, reported significantly higher sense of presence for the remote user and it was easier to perceive nonverbal cues easier.	AR provides: (a) Seamless interaction between real world and virtual environment; (b) ability to enhance reality; (c) Support for tangible interface metaphor; (d) ability to transition between real and virtual world.
Blake and Butcher- Green (2009)		n=46 female	This article discusses: Learning by scaffolding; Agents that know their environment and are able to adapt; Using emotions during feedback; Vygotsky's Zone of Proximal Development; Learners can self-regulate their training session; Adaptable learning; Agents in a sense of intelligent system with knowledge database; and Decision making.	Experiment was conducted over a two-day period. Day 1: 46 females (ages 11- 14) were given training on how to use the AR scaffolding system. Day 2: 10 participants were chosen based on their performance during the first experiment and divided into two groups: group where adaptive scaffolding was used and where removal of aids is tailored in real-time to the trainee and a group with passive scaffolding system in which the aids were statically and systematically removed.	Students who received adaptive scaffolding performed better than group who received passive scaffolding.

Table A1 (Continued)

Dunleavy et al. (2009)		6 teachers and approximatel y 80 middle	The purpose of this study was to document how teachers and students describe and comprehend the ways in	The lesson was designed to teach students math, language arts, and scientific literacy and it was delivered in a	Learning outside was highly motivating, authentic and presented a novel way to learn math.
		and high school students.	which participating in an augmented reality (AR) simulation aids or hinders	narrative-driven, inquiry- based format (Dunleavy et al., 2009). This experiment	This type of learning promoted collaboration.
			teaching and learning a mobile AR application Dunleavy et al. (2009).	was not conducted in the classroom setting, but in the open where students moved	Previously disengaged students became active participants.
			2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	around the school playground, and used their handheld computers to display text, video, and audio files when they approached certain physical locations on the map.	Future research should focus on how teachers adapt the curriculum and what factors affect the kinds of adaptations that are made.
Haniff and Baber (2003)	Cognitive Load	10 post- graduate students	Augmented Reality (AR) systems need to be evaluated for their appropriateness for a given task.	The WART system is compared with a paper version of the assembly instructions.	It took less time completing the task with the paper-based instructions than the AR system.
					AR needs to get better technologically.
					Paper instruction was better than AR.
					Paper instruction caused more mental load.
					AR offered fuller representation.
					Users appreciated AR more.

Table A1 (Continued)

Hsiao et al. (2010)	n=1211	Hsiao et al. (2010) explored an unusual but culturally relevant application of AR in learning environments – learning with AR while exercising.	This study used 1211 seventh grade students who were divided into five groups: first three groups were exercise and AR based and they included games group, learning group and an amalgam of games and learning group. Fourth group was a keyboard/mouse based computer assisted instruction (KMCAI) and the fifth group utilized traditional face-to- face classroom instruction.	Students with AR did not learn less compared to their counterparts in the traditional classroom. No statistically significant difference between two treatments, except for gaming AR group which performed poorly on test results. Future research should provide sufficient familiarity with the environment to reduce any novelty effects and begin to emphasize the more valuable learning characteristics of AR (Hsiao et al., 2010)
Juan et al. (2008)	n = 40, Ages 8-10	Comparison of traditional spatial display (LCD monitor) with a HMD device.	Students were divided into two groups: HMD and LCD group and were administered AR treatments. The AR system was designed to teach anatomical structures of the human body and it allowed tactile user interaction with the users	No statistically significant difference between two treatments. No statistically significant difference on the order of exposure to the treatment. Participants liked both treatments. The researchers, based on the experiment results, will continue implementing and considering AR in education.
Krevelen & Poelman (2010)		This literature discussion explains various components of AR systems such as displays, tracking, user interface and applications of AR.		

Table A1 (Continued)

Leblanc et al. (2010)	Learning	n=28, n= 7	The aim of this study was to compare the human cadaver model with an augmented reality simulator for straight laparoscopic colorectal skills acquisition.	Study participants were divided into AR simulator group and a human cadaver group and were compared according to their technical skills, event scores, and satisfaction with the training model.	Higher scores reported with AR treatment. Higher satisfaction when using cadaver reported. AR should be used for pre-training.
Vilkonienė (2009)		n=114	This study analyzed the influence of AR technologies on student knowledge about human digestive system.	Vilkoniene (2009) divided the students into three groups: AR, computer program and lecture group which delivered the same lesson about human digestive system.	While studying human digestive system, AR lesson positively enhanced student learning when used in traditional classroom setting with traditional teaching aids.
Yu et al. (2010)			This literature discussion discusses tracking systems, medical applications, mobile applications, visualizations and AR, industrial applications, edutainment, and hardware requirements for AR systems.		Recommendations for future research: AR systems must be able to process vast amounts of information available in the real world. Tracking needs improvement and equipment needs to get smaller. Additionally, HMD technology needs to be perfected.
Appendix A, References for Research Studies in Augmented Reality

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APPENDIX B: SURVEY OF RESEARCH STUDIES IN AUGMENTED REALITY AND COGNITIVE LOAD

Author / Study	Theoretical grounding	Subjects	Purpose / Hypothesis	Methods / Treatments	Results
Chen et al. (2009)	Cognitive Load Theory	n=58	Chen et al. (2009) state that the purpose of this study is to explore whether presence under different augmented reality (AR) displays differs and how presence may affect student learning.	Experimental design contained two conditions: head-mounted display and webcam display. 2 groups: HMD & Web cam display	Different interfaces did not produce different presence. Presence was not the predictor of the learning performance, neither of the total cognitive loads. Presence significantly affected the AR cognitive load. Students who had higher level of presence would possess lower cognitive load when they were interacting with AR. Level of involvement was a predictor of the level of presence. Study findings: Webcam vs. HMD – No statistically significant difference. HMD may lead to higher presence. Presence did affect students AR cognitive load, which implies that students possessing higher feeling of being there may help them understand AR 3D representations more
					Students also said that AR will be helpful tool for them to learn chemistry and that it was fun to play with the AR markers.
					Future studies should focus on how to integrate AR into the classroom or instruction setting, either from a pedagogical perspective or technological perspective.

Table B1 Research studies that focus on augmented reality and cognitive load

Table B1 ((Continued)
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Huang et al. (2010)	E1: n=190 E2: n=76	Huang et al. (2010) investigated learners' attitudes towards VR environments in two case studies	Case study 1: The study participants were 167 undergraduate students who completed a 16-item likert	Case study 1: learner motivation as well as the problem solving capability of the environment does indeed increase in 3D VR environment.
		The first case study was conducted with a Web- based 3D VR virtual body learning system that was used to teach undergraduate medical students about the structure of the human body.	Case study 2: Participants in this study were 76 medical students who took the 25- question likert scale test.	Case study 2: interaction, immersion and imagination were all predictors for the collaborative learning. Virtual environment can be successfully used for collaboration and problem solving tasks while maintaining high levels of student motivation.
		The second case study was performed with a 3D human organ learning system that operated in two modes: single user self-learning mode and collaborative learning mode.		effectiveness of using VR learning environments.
		H1: With increased immersion and imagination provided by VR, motivation of the learners will increase as well as the problem- solving capability of the environment.		
		H2: It was hypothesized that this system (CS2) will positively impact student collaborative learning from three aspects: interaction, immersion and imagination.		

Kim and Dey (2009)	Cognitive Load Theory	n=24 12 elderly drivers 12 younger	Kim and Dey (2009) explored an issue of declining spatial cognition with aging automobile	To determine if AR can help aging drivers, Kim and Dey (2009) employed 24 drivers, from which 12 were elderly	Results: drivers using AR system had significantly fewer navigational errors and divided attention related issues when compared to regular display.
		drivers	drivers with the use of simulated AR windshield display.	drivers over the age of 65 and 12 younger drivers.	H1: When driving while dependent on any navigation system, elder drivers will exhibit worse driving performance and more issues
			Spatial cognition ability declines with age.		of divided attention than younger drivers. Statistically significant differences were found.
			Can AR help aging drivers?		
			Researchers wanted to find		H2: When using simulated AR windshield display, the drivers will exhibit better
			out whether using AR		driving performance and fewer issues of
			display (windshield		divided attention, than when using a typical
			navigational system) will		in-car navigation device with a 2D bird's
			performance and fewer		significant differences were found
			issues with divided		significant anterences were round.
			attention. Also, Kim and		H3: When using simulated AR windshield
			Dey (2009)		display, elder drivers will exhibit better
			Wanted to find out whether		driving performance and fewer issues of
			elder drivers using the AR		divided attention than when using a typical
			driving performance and		eve view man
			fewer issues with divided		Display. Statistically significant differences
			attention compared to using		were found.
			the non-AR display.		
					For future research, researchers would like
					evaluation and explore more focused
					design guidelines for supporting older
					people's navigation preferences and
					perceptual abilities.

Klatzky et al. (2008)	Cognitive Load Theory	E1: n=12 E2: n=10 E3: n=10	Klatzky et al. (2008) examined the impacts of AR visualization tool when compared to the conventional ultrasound	Three experiments were conducted in this study to examine the impacts of AR visualizations.	The Sonic Flashlight showed higher accuracy and lower variability in needle aiming than CUS did in all three experiments.
			procedure of guided needle insertion. This is another interface comparison study in which two interfaces are compared and cognitively	First experiment (n=12) examined the learning of through plane needle insertions that were guided by the two interfaces (CUS and	Study participants did not have to cognitively mediate visual and spatial representations since the Sonic Flashlight eliminated the need to do so.
			assessed.	Sonic Flashlight).	AR treatment proved better than CUS interface because it eliminated the need to
				The second experiment was similar to the first experiment, but the needle insertion points	build spatial visualizations, thus relieving the cognitive load (Klatzky et al., 2010).
				were differently positioned.	For the future research, it would be beneficial to determine if variability in
				The third experiment utilized in-plane needle insertions (in- plane is referred to ultrasound	training will alleviate the narrowness of learning observed here.
				field of view) to further reduce the need for cognitive	
				mediation to represent target location.	

Table B1 (<i>Continued</i>)
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Tang et al. (2003)	n=75 54 male, 21 female	This study describes an experiment that tested the relative effectiveness of AR instructions in an assembly task.	Study included 75 participants (university undergraduates) who were divided into four groups: printed media (n=19), CAI on LCD monitor display	Study results indicate that there was no significant advantage for AR treatment in the terms of time of completion over CAI and HMD treatments.
			(n=18), CAI on a see-through HMD (n=19), and spatially registered AR via see-through HMD (n=19).	Significant statistical difference was observed between paper and AR treatment as participants completed the AR treatments on average several minutes before paper
			Instructional materials were 56 procedural steps assembly task, and for each step subjects had to acquire a specific color and size part and orient it to the	instruction group. AR improved task performance and can relieve mental workload on assembly tasks.
			current subassembly according to the assembly instructions.	AR increased task accuracy.
			What was measured was if AR can improve human performance during an assembly task when compared to other media (printed media, CAI, HMD), determine theoretical basis for cognitive support AR provides and to find any weaknesses of the current AR interface design methodologies.	Future research: Designers seeking to make use of the performance gains of AR systems also need to consider how the user manages their attention in such systems and avoid over-reliance on cues from the AR system.
			To measure these, researchers analyzed the participants' task performance (time for completion and accuracy of the task), and perceived mental workload using the NASA TLX cognitive load test.	

Table B1 (Continued)
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Wang & Dunston (2006)	Cognitive Load Theory, Working memory limitations, Spatial cognition	n=16 Graduate students	Wang and Dunston (2006) study aims to (a) examine the feasibility of augmenting human abilities via Mixed Reality applications in construction tasks from the perspective of cognitive engineering, (b) acknowledges the ergonomics features and research issues in MR systems, and (c) generates partial guidelines to solve ergonomics issues. AR can attach required information to workers real world and release part of working memory that is occupied with extraneous items thus reducing the CL.	Study participants were 16 graduate engineering students who attended both treatment sessions (HMD and monitor) and completed two possible sequences of two treatments. Treatments comprised orientating a fiducial marker to a position where the overlaid virtual model (piping) oriented to the specified orientation indicators.	 H1: Confirmed – HMD reduced the amount of time required to complete the task. H2: Confirmed – HMD increased accuracy. H3: Confirmed – HMD reduced cognitive load. AR systems can improve physical task performance and can relieve mental workload. Using HMD rather than monitor yielded shorter completion time, reduced orientation displacement and reduced cognitive load. Results of this experiment could be used for design of future AR systems.
			 H1: When compared to traditional monitor, using HMD will reduce the amount of time to complete the task, H2: When compared to LCD monitor, using HMD should improve the accuracy, and H3: When compared to LCD monitor, HMD should reduce the cognitive load. 		

Yim & Seong (2010)	Cognitive Load Theory, Working memory limitations	n=42	Yim and Seong's (2010) double study measured the optimum amounts of information to be delivered in a chunk during a training session without overloading learners' working memory (experiment 1). For the second experiment, Yim and Seong (2010) wanted to determine what types of information enhance the learning ability of novices and to suggest heuristic guidelines by which to make effective AR training instructions. The purpose of this study was (a) determine optimum amounts of information in a chunk in the AR training environment; (b) determine effect of information from experts such as prediction & principles on novices.	In the first experiment, 42 graduate students were assigned to 7 groups, who were further divided into 4 groups. All 4 groups assessed optimal chunking. 3 groups assessed the most suitable types of information to be presented in AR learning environment. The second experiment was designed to determine the efficiency of heuristically suggested guidelines based on 9 principles for reducing cognitive load from the Cognitive Theory of Multimedia Learning. Study participants were 15 graduate students who were split into 3 groups with the following three AR treatments: AR lesson based on sequential procedure, AR lesson based on 9 ways of reducing cognitive load as outlined by Mayer and Moreno (2003), and heuristically based AR lesson which used CTML as template for its own design.	Results of the experiment 2 did not yield statistical difference between three treatments, but t-test did reveal slightly better performance of students who were in the suggested heuristic guidelines group over CTML group. Another finding was that learners displayed high interest when interacting with the AR system and this reflected on learning efficiency.

Appendix B, References for Research Studies in Augmented Reality and Cognitive Load

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APPENDIX C: SURVEY OF RESEARCH STUDIES IN AUGMENTED REALITY AND SPATIAL ABILITIES

Author	Theoretical grounding	Subjects	Purpose/Hypothesis	Methods / Treatments	Results
Chen (2006)		n=184 Average age = 16.45	 Chen (2006) examined the effects VR based learning environments have on learners who possess different spatial abilities. Chen (2006) wanted to know if there were any difference in test scores and interaction between learners with high and low spatial visualizations in three treatments: guided VR treatment (n=64), non-guided VR (n=58), non VR treatment (n=58) which consisted of lectures and reading materials (control group). Spatial ability is a psychometric construct with two major factors: spatial orientation and spatial visualization (Michael, Guilford, & Fruchter, 1957). 	 184 adolescents were divided into three different learning groups (guided VR, non-guided VR, and non VR) and presented with the novice car driver instruction lesson. This study utilized pre-test and post-test quasi experimental design where the study participants were given content pre-tests, Bennett, Seashore and Wesman Space Relations Test (Chen, 2006) as well as the 15 question post-test after completing the driving lesson. The driving lesson was designed to assess student understanding of the traffic rules. H1: Is there a difference in gain score for the VR-based test between the low spatial visualization ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)? 	 H1, H2 and H3 - statistically significant difference in gain scores exists among the low and high spatial visualization ability learners in three groups. There were no significant score gains between the high and low spatial visualization abilities learners. Spatial abilities did not play any role in these experiments. Guided VR group achieved the best scored. There has been little research on how learner characteristics interact with the features of virtual environments either to aid or inhibit learning.

Table C1 Research studies that focus on augmented reality and spatial abilities

Ekstrom, French, Harman,	H2: Is there a difference in gain
and Dermen (1976) defines	score for the VR-based test
spatial orientation as a	between the high spatial
measure of the ability to	visualization ability learners of
remain unconfused by	each learning mode (Guided VR,
changes in the orientation of	Non-Guided VR, and Non VR)?
visual stimuli, and therefore it involves only a mental rotation of configuration. -McGee (1979) defines spatial visualization as a measure of the ability	H3: Is there a difference in gain score for the VR-based test between the high spatial visualization ability learners of the Guided VR mode and the low spatial visualization ability learners of the same mode?

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Cohen (2005)	Spatial abilities and cognition	n=6 graduate students	Cohen (2005) study investigated the problem solving strategies of learners with high and low spatial abilities.	Study participants were 6 graduate students (3 high and 3 low spatial abilities) who were screened for spatial abilities by using the Guay-Lippa Visualization of Viewpoints spatial abilities test and the Vandenberg Mental Rotation Test (Cohen, 2005).	High spatial ability students used the available animation more often that the low spatial ability students.High spatial abilities learner used more physical and spatial detail when explaining the details of the stimulus object and they drew more accurate representations of the intersection of the egg shaped stimulus.
Dunser et al. (2006)		n=215 High school students	Researchers explored the potential of AR application to train spatial abilities.Spatial ability is one of the main aspects of human intelligence and it is very important for several occupations or ed. Programs and trainings.Oman et al. (2002) studied how people learn to rotate simple object configurations. Researchers found that people more likely imagine moving themselves then than rotating the object around them. Oman et al. (2002) suggested that VR is excellent tool for spatial training.Research question: can AR be used to train spatial ability and which aspect of spatial ability can be trained?	 Dunser's et al. (2006) tested four interfaces on four groups. 1. First group was a Construct3D group (n=47) (3D geometric construction tool that used collaborative AR setup with see through HMD). 2. Second group (n=44) used a CAD3D program that was a computer aided design program with computer monitor and a mouse. 3. Third and fourth groups were control groups. One control group had geometry classes (n=66) in school and other did not (n=58). 	No clear evidence on the effectiveness of AR as a spatial ability training tool. No clear advantage in geometry learning. AR can be used to develop useful tools for spatial ability training. New tools to measure spatial ability in 3D environment are required. Future studies should also take gender differences into account.

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Hedley (2003)	Spatial abilities	n=101	Hedley (2003) explored the acquisition and human processing of spatial knowledge.	2 groups: geography models + pc + monitor and geography model + AR marker + HMD	Advantages found by AR users over desktop users were attributed to the multisensory interactions AR interface provides.
					AR use seems to result in higher level of detail in representations those desktop interface users.
					AR provides an increase in completeness and level of detail in representations of geographic visualization over desktop interface.
					Evidence in this experiment suggests that coupled visual & sensory-motor feedback that AR provides, results in a sort of cognitive saline of reinforcement, producing an anchor point like node in internal representations.
					Through multisensory interactions, AR may spread cognitive load for users, thereby reducing cognitive inertia.
					AR contributed to improvement in conceptual & factual understanding. For future research, it would be beneficial to develop a working knowledge on how interface components influence learners and understanding of geographic knowledge. Also, understand what kinds of spatial features have what kinds of cognitive signals and determine the factors that amplify or
					determine the factors that am modify it.

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Huk et al.	n=125	Huk et al. (2003) investigated	Participants were divided into two	Learner's preference of treatment
(2003)		the influence of visual spatial	groups: biology lesson that	(2D and 3D) was indeed influenced
		ability on the attitude of users	contains QuickTime VR 3D	by student's spatial abilities.
		towards video and 3D	models and same biology lesson	
		animations in learning	but without the VR models and	Students with higher spatial
		environments.	with 2D images in place.	visualization abilities preferred animation and 3D while students
			Participants were given Stumpf	with low spatial visualization
			and Fay spatial abilities test as	abilities preferred simple 2D
			well as the post-treatment likert	representations.
			scale survey which assessed	
			learner attitudes.	Preference for simple mode of
			Materials: CD ROM with Cell 2	cognitive load
			Mitochondria and catabolic	cognitive ioud.
			metabolism lesson.	
			2 versions of the learning	
			materials: one with QuickTime	
			VR and other treatment without	
			VR	

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Kozhevnikov et al. (2007)	Spatial abilities	E1: n=60 E2: n=17 (8high, 9 low) E3: n=15 (9 high and 6	Kozhevnikov et al. (2007) conducted three studies that examined the relations of spatial visualization to solve physics problems in the area of kinematics.	The first study used 60 physics novice undergraduate students who were given a pre-test, spatial abilities test, the Form Board Test and multiple-choice kinematics test.	Results of all three studies concluded that a significant correlation exists between students' spatial abilities and overall accuracy of their solutions to kinematics problems.
		low)		The second study used 17 students (8 high and 9 low spatial ability learners) who were given the same problem as students in experiment 1 and were also instructed to "think aloud" while solving open-ended versions of the kinematics problems.	Additional findings for study 2 indicated that low spatial abilities students constantly neglected the importance of motion components, which Kozhevnkov et al. (2007) suggests that they tend to choose those solutions that tax their visual spatial working memory less.
				The third experiment used 15 undergraduate students (9 high and 6 low spatial abilities learners) who were given kinematics graph problems with 2D motion extrapolation problems.	Students with high spatial visualization abilities performed better.

Mark (1993)	Mark (1993) classifies spatial	Sources of spatial information:	Sensorimotor and haptic perception
	knowledge according to its	haptic spaces, pictorial spaces and	is the most important early form of
	nature, sources of spatial information and human	transperceptual spaces.	spatial information that reaches the mind.
	interaction with the world and	Declarative geographic	Pictorial spaces are based primarily
	associated linguistic use.	knowledge could also be called 'geographic facts' (Freundschuh,	on visual perception, although the auditory and olfactory senses also
	Nature of spatial knowledge	1991).	contribute to a pictorial concept of
	procedural and	Configurational knowledge is	space.
	configurational.	"map-like", and often has or approximates a Euclidean geometry.	Transperceptual space is composed or assembled in the mind from a number of independent haptic or
			pictorial spaces or objects
		Procedural knowledge of geographic space is evidenced by	experienced over time' (Mark, 1992).
		ways from location to location.	

McGee	According to McGee (1979),	McGee (1979) found the following:	
(1979)	the purpose of this article is	1. Two distinct spatial abilities ex	ist:
	threefold:	spatial visualization and orient	ation.
	(a) to summarize	2. Visualization and orientation	atad
	psychometric studies of	with success in a number of	ated
	human spatial abilities, (b)	technical vocational and	
	examine the consistencies and	occupational domains than is y	erbal
	disagreements in relation to	ability, which makes them imp	ortant
	the hypothesis that sex	variables in applied psycholog	y.
	differences in various aspects	3. Sex differences in various aspe	cts of
	of perceptual-cognitive	perceptual-cognitive functionin	ıg
	functioning are a secondary	(e.g., mathematics and field	
	consequence of differences	consequence of differences with	h
	with respect to spatial	respect to spatial visualization	n and
	visualization and spatial	spatial orientation abilities.	and
	orientation abilities,	4. Sex differences on tests of spat	ial
	(c) review the literature with	visualization and orientation as	well
	reference to environmental, genetic, hormonal, and neurological influences that	as on numerous tasks requiring	these
		abilities do not reliably appear	until
		puberty.	
	interact in producing	5. Spatial ability is influenced alr	iost
	individual variation in spatial	as much by genetic factors as i	3
	test scores.	studied	
		6 The development of sex differ	nces
		in spatial skills is likely related	to
		sex differences in the develop	nent
		of hemisphere specialization.	light
		cerebral hemisphere is speciali	zed
		for spatial processing and that	males
		have greater right hemisphere	
		specialization than females.	

Table C1	(Continued)
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Miyake et al.	n=167	According to Miyake et al.	167 participants performed	Miyake et al. (2001) states:
(2001)		(2001), this study examined	visuospatial short-term memory	"Confirmatory factor analysis results
		the relationships between	(STM) and WM span tasks,	indicated that, in the visuospatial
		visuospatial working memory	executive functioning tasks, and a	domain, processing-and-storage WM
		(WM) executive functioning,	set of paper-and-pencil tests of	tasks and storage-oriented STM tasks
		and spatial abilities.	spatial abilities that load on 3	equally implicate executive
			correlated but distinguishable	functioning and are not clearly
		Direct link for link between	factors (Spatial Visualization,	distinguishable. These results provide
		Spatial abilities, working	Spatial Relations, and Perceptual	a contrast with existing evidence
		memory and the central	Speed).	from the verbal domain and support
		executive.		the proposal that the visuospatial
				sketchpad may be closely tied to the
		The second goal of the		central executive."
		present study was to specify		
		the relations		
		between WM and traditional		
		psychometric spatial abilities.		

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Shelton (2003)	Spatial abilities	Phase 1: n=33 Phase 2: n=15	How students change the way they come to understand topics, which involve dynamic spatial relationships while interacting with virtual objects (AR).	Quantitative statistical analysis for the phase 1 of the experiment (n=33) included pre and post-test, Wilcoxon signed rank analysis, videotape analysis of student AR activity, analysis of pre- and post- assessment interviews, and reflection interviews 3 weeks	 H1: Instructional AR requires activity among participants for increased knowledge acquisition. Confirmed. H2: Visuo-motor activity leads to expert knowledge of seasonal variation of light and temperature is linked to learning of dynamic spatial relationships. Confirmed. H3: Blending of reality and virtually
				after the initial exercise. Study findings confirmed the original hypothesis and concluded	holds unique advantages for teaching and learning. Confirmed.
				original hypothesis and concluded	AR requires interaction.
				that AR interface indeed changed the way students understand earth-sun relationship.	Visuo-motor activity is linked to learning about spatial abilities and leads to better understanding.
					For future research, a follow up study that uses AR in a variety of topics that involve 3D dynamic spatial relationships (molecular interactions, geographical land formations, earth-sun relationship, moon phases and tide cycles, eclipses, solar system configurations, galaxy distributions etc., should be conducted.
					Models/lesson: Rotation/Revolution, Solstice/Equinox, Seasons A second resource for building the questions was the previous research at Indiana University, led by Sasha Barab. The two studies that described the implementation of similar Earth-sun topics in a desktop 3D world (Barab et al., 2000; Barab et al., 2001).

Table C1 (Continued)

Chalter P	Creation 1		Descendence have the size d	20	1	Student on denoted din a sense aller
Shellon &	Spatial	n=34	that AD interface would	students were given concents of	1.	improved in all assas following
(2002)	admittes		change the way students	students were given concepts of		A D intervention
(2002)			change the way students	colotion and again and account	2	AK intervention
			knowledge in a whole new	soluce and equinox and seasonal	۷.	miginterpretation of factual
			knowledge in a whole new	Passanahara analyzad student		information was reduced after
			way.	performance change from pre-test		intervention.
			To measure effect AR exercise had on students	to post-test, students score	3.	Largest increase in improvement was registered for those with
			researchers proposed 3	topics was the student		lower pre-assessment scores
			questions:	performance affected	4	Majority of students chose to
			1 How did student	performance arrected.		draw sketches to help illustrate
			nerformance change			their understanding of earth-sun
			from pre to post			relationship
			assessment?			relationship.
			2. Which students improve		Fu	ture research should examine how
			and which did not?		to	methodologically tie student
			3. For which topics was		act	tivity with the interface to their
			student performance		ch	anges in understanding.
			affected?			

Shelton & Hedley (2004)	 AR may have unique and powerful link to spatial knowledge acquisition through visio-motor involvement in the processing of information. Researchers identify key properties of AR and how they differ from traditional interfaces. From spatial perspective, AR interface releases one from being detached from 3D content through desktop metaphors and the inherent ambiguity between mouse clicks and buttons on screen. AR builds on spatial cognition, animate vision & vision theory Shelton & Hedley (2004) To move or rotate object in VR, one must cognitively transform these operations (move mouse, click button, set orientation, process result). AR users produce greater levels of completeness in representations. 	Literature states 3 types of spatial knowledge provided by AR: Mark's (1993), Golledge and Stimson (as cited in MacEachren, 1991) and Wickens and Hollands (2000) first classification of spatial knowledge is based on the nature of spatial knowledge, and it consists of declarative (landmark knowledge in Wickens & Hollands, 2000), procedural (route knowledge in Wickens & Hollands, 2000) and configurational (survey knowledge in Wickens & Hollands, 2000) spatial knowledge. AR interfaces constitute some combination of procedural or configurational knowledge. Procedural because some AR interfaces allow you to fly into 3D display. Configurational due to the learner's ability to hold 3D landscape like a map. Various theories and concepts: 1. Multiple encoding. 2. Most physically active students were the most successful in learning with AR. 3. Schema theory- schemas can be built and activated through information presentation closely resembling the structure of particular schema. 4. Spatial Cognition theory 5. Animate vision theory-links visual concept acquisition to acting and moving.	Future research should examine direct comparison between the instructional design presented in this study with AR, and more traditional techniques is needed to determine if students who used AR can outperform the students who used traditional learning techniques. -Follow up study should use AR in variety of topics that involve 3D dynamic relationships, such as learning about molecular interactions or geographical land formations. Research needs to look at the design of the visual representations (3d objects) in aspects of movement, color, and size.

Table C1	(Continued)	
1000001		

Wang, Chang & Li (2007)	n=23	Wang (2007) explored the comparative effects of using web-based tutorials differentiated in including either 2D representation or interactive 3D representation on the influence of spatial visualization ability of undergraduate students	Wang et al. (2007) study used 23 undergraduate students, separated in two groups: 1. 2D (n=10) and 2. 3D (n=13) group Both groups were presented with a Web based system, which incorporated multiple media representations which were aimed at facilitating learners' spatial reasoning skills.	No significant statistical difference was found between student's pre- and post-test scores on the spatial visualization abilities tests, but researchers did observe a medium effect size for 3D group in terms of practical significance. The results of this study imply that different modalities of media representation (2D and 3D) are likely to influence students in different ways and Wang et al. (2007) do call for a replication study due to their small sample size.
				For future research, researchers call for study replication with a larger sample size.

Tah	10	C1	(Continued))
1 40	ιc	$\mathcal{C}I$	(Commune)	,

Yang et al.	Spatial	n=415	Yang et al. (2003)	The experiment consisted of two	Instructor guided animation
(2003)	visualization abilities	undergraduat e students	investigated the impacts of animation on student learning	treatments: computer animation treatment with 228 students and	instructions performed better than static diagrams.
	ucilities	• 50000000	and whether animation	still diagram treatment with 161	
			impact was determined by	students.	Animation was more helpful to
			student spatial abilities.		students who possessed higher spatial
				Each treatment group was taught	abilities.
				by an associate professor who	
				lectured the students on chemical	
				concepts of now batteries	
				generate electricity.	
				Researchers used 44 item	
				American Chemical Society'	
				California Chemistry Diagnostic	
				Test as a baseline diagnostic test	
				to assess student knowledge of	
				chemistry, and two one hour	
				exams administered before the	
				initial differences between the	
				two treatment groups and as	
				covariates in the analysis of the	
				dependent measures. In addition,	
				pre and post-tests were	
				administered to measure the	
				knowledge gains before and after	
				the treatment and finally, a	
				Purdue Spatial Visualizations test	
				was given after the treatment to	
				obtain a measure of students'	
				spatial abilities.	

Appendix C, References for Research Studies in Augmented Reality and Spatial Abilities

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APPENDIX D: SURVEY OF RESEARCH STUDIES IN AUGMENTED REALITY AND TACTILE SENSORY INPUT

Author	Theoretical grounding	Subjects	Purpose/Hypothesis	Methods / Treatments	Results
Fjeld et al. (2002)	Affordances, Tangible user interface	n=30 undergraduate or graduate students 13 female 17 male Ages 20-36	 Fjeld et al. (2002) compared an in-house designed Tangible User Interface (AR application), with two alternative single user tools, which consisted of a 3D physical model and a 2D cardboard model of the same treatment. H1: Cardboard gives less cognitive support than Physical Blocks H2: Cardboard gives less cognitive support than BUILD-IT. H3: BUILD-IT gives less cognitive support than Physical Blocks. 	Researchers measured trial time to complete the task, number of user operations (cognitive support), learning effect in both preceding variables (cognitive support), and user satisfaction. 10 participants were assigned to each treatment (a) Physical model; (b) AR; and (c) cardboard).	 Physical 3D tool significantly outperformed 2D cardboard treatment in time to complete as well as the cognitive support. Physical 3D tool also outperformed the AR tool, but only in user satisfaction, while time to complete difference was not statistically significant. Some considerable but not statistically significant learning effects were observed with AR tool in trial time and the amounts of blocks tested. Mean time to complete test: AR buildit-2 minutes Physical blocks 18 seconds Cardboard 3 minutes 30 seconds Math 26 minutes H1 – True; H2 – True; H3 – False Tool design in this study was inspired by decision support techniques. For future research, it may be worth to examine how each of these techniques can predict cognitive support of a tool.

Table D1 Research studies that focus on augmented reality and tactile sensory input

Hornecker and Dunser (2009)	n=11 n=23	Hornecker and Dunser (2009) completed a study on the use of AR "Magic Book" and how young children reacted and interacted with the physical objects that are augmented with digital 3D objects.	Participants in this study were children (6-7 year old) who were divided as follows: 4 pairs and 3 children experimented with the "Sun" story, and 10 pairs and 3 individual children experimented with the "Chick" story.	Children who worked collaboratively took less time and showed more signs of enjoyment such as laughter and general play (Hornecker & Dunser, 2009). Children expected digital augmentations to behave as real objects.
		Researchers designed two "Magic Book" stories, which were essentially combination of physical paper pages and desktop interactions (screen and mouse), which replaced	Researchers performed qualitative statistical data collection and analysis.	Affordances offered by the paddles, which became physical interaction devices between AR and physical worlds, invited actions that were not accounted for by the designers of the system.
		traditional narrated text pages with animated interactive sequences.		Hornecker and Dunser (2009) point out that it is not always evident how users will perceive and interpret physical input
		Children were required to manipulate paddles with AR fiducial markers and control the story's main		opportunities since everyone is unique when it comes to life experiences.
		characters by physically moving the paddles.		

Jones et al. (2006)	CLT	n = 36 middle and high school students 21 females, 15 males; 72% White, 23% African American, and 5% from other	Jones et al. (2006) investigated the impact of haptic augmentation of science inquiry program and how addition of haptic feedback influenced students learning experience. Jones et al. (2006) points out that more immersive learning environment that not only	 36 middle and high school students were randomly assigned to three tangible interface groups: 1. computer mouse, 2. Sidewinder joystick and 3. PHANTOM haptic device. Jones et al. (2006) wanted to determine if there were any differences by instructional 	Results showed that the addition of haptic feedback from the haptic- gaming joystick and the PHANToM indeed made a difference. Learning environment was more engaging, and it allowed students to construct their own knowledge.
		ethnic groups	made instruction more engaging, but may also influence the way in which students construct their	treatment for students' knowledge of virus characteristics and student	device, the more students used haptic terms to describe the virus.
			understanding of abstract scientific concepts.	attitudes towards the instructional treatment.	Haptic augmentation has potential to expand students' learning and
			Dual coding theory (Paivio) suggests that information may be encoded in ways that	Haptics is oriented towards encoding of substance (microstructure) while vision is oriented towards encoding	has the potential to offer a variety of new and engaging hands on experiences.
			move beyond verbal pathways.	of shape (macrostructure). Exploratory procedures: instinctive movements to	Touch is great and more effective than passive representations.
			Each modality has its own working memory and employing multiple	explore objects. Research questions:	Hands on & minds experience leads to more meaningful experience.
			modalities can reduce cognitive load.	1. Are there any differences caused by the instructional treatments	Touch is often described as active discovery sense.
			Goal of this study was to examine efficiency of different types of haptic	joystick, mouse) on students' knowledge of virus characteristics?	Future research should confirm the findings of this study.
			interfaces when compared to traditional instruction.	2. Are there differences caused by the instructional treatments (PHANTOM, haptic joystick, mouse) on students' attitudes toward the instruction?	-

Klahr et al. (2007)	56 seventh and eighth graders	This study is an extension of Triona and Klahr (2003).	Klahr et al. (2007) used 56 7th and 8th graders (20 girls and 65 boys; M=13.1	All four conditions were equally effective in producing significant gains in learners' knowledge about
	20 girls and 50	First extension: Klahr et	years, SD=0.09 years).	design optimal cars, and in their
	0093	al. (2007) used discovery	For their experiment, Klahr et al. (2007) used physical	confidence of their knowledge.
		instruction.	and virtual mousetrap cars.	One factor that was statistically significant was time.
		Second extension: Use	Study participants were	e
		older student population (8 th graders)	divided into 2 groups (physical and virtual lesson) and tested with	Klahr et al. (2003) point out that the most surprising discovery of their study was the fact that physical
		The purpose of Klahr et al. (2007) study was to determine the effects of putting learners' hands on virtual rather than physical materials in a scientific discovery context.	fixed amount of time and fixed amount of cars they could construct.	virtual distinction had no effect on the quality of children's answers to the final open-ended questionnaire item ("What else do you think would be important for building a distance car?"). Klahr et al. (2007) expected the children in the physical group be more experienced and with deeper nuanced understanding of the underlying physics of the mousetrap cards, but the analysis of the final questions did not gave support to this hypothesis.
				Future Research: Klahr et al. (2007) point out that much remains to be learned about learning efficiency of
				physical and virtual learning materials when they are used in different domains, with different instructional goals, outcome
				measures, and type of students.

Marshall	Developmental	NA	Marshall (2007) points	According to Piaget (as	Future research: If tangible
(2007)	theory (Piaget),		out several benefits of	cited in Marshall, 2007),	interfaces are to be used to design
	Constructionism		using tangible interfaces	manipulation of concrete	systems for learning, it is critical
	(Papert)		during learning:	physical objects supports	first step to demonstrate the benefit
			a) using physical	learning & thinking in	of using physical materials.
			materials in learning	young children.	
			might change the		Call for more comparative
			nature of knowledge	Tangible interfaces might	empirical studies.
			gained compared to	be suitable for	
			knowledge gained	collaborative learning.	Abandon claim that physical
			through interaction		interfaces are good for learning.
			with virtual materials,	Types of learning possible	
			b) tangible interfaces	with tangible interfaces:	Research is required to investigate
			nay support more	process of discovery &	for physical manipulation
			through tactile	representations & artifacts	for physical manipulation.
			interaction	representations & artifacts.	Empirical studies comparing effects
			c) tactile interaction is	Growing body of literature	of physical and non-physical
			assumed to be more	in cognitive sciences	version of the same task are
			natural and	suggests stronger links	uncommon.
			d) tangible interfaces	between physical activity	
			may be useful in	& cognition.	
			collaborative	J	
			learning.		

Table D1	(Continued)

Minogue et al. (2006)	NA	n=80 middle school students 37 females 43 males	A study by Minogue et al. (2006) explored the impact of haptic augmentation on middle	Pre- and post-test control group design in which the participants (n=80) were randomly assigned to one	There were significant differences in pre-test and post-test scores on all cognitive items.
			school students' conception of the animal	of the two treatment groups $(n=40 \text{ per group}).$	Learning did occur in both groups.
			cell.	Both groups used the same learning content (cell exploration), but with different modalities.	Students benefited from the affect which an affective benefit of haptic technology caused by addition of haptic feedback which has been shown to have positive impact on user interest, attitudes and abilities
				The first group received two modality instructions (visual and haptic) while	to navigate in 3D environments (Minogue et al., 2006).
				the control group only received lesson delivered in visual modality. -According to Minogue et al. (2006), the cell exploration program placed	Researchers did not find any impacts of participants' cognition due to the intentional limitations imposed by some of the assessments used in the study.
				the student into a semi- immersed environment and it allowed the student to interact with the learning content (rotate and zoom).	Future research: Minogue et al. (2006) suggest further exploring the use of haptic interfaces, how they impacts learners cognitively and affectively, and how students perceive, process, store, and make use of haptic information in various educational concepts.

Persson et al. (2007)	Various cognitive theories	23 subjects 13 women 10 men	Persson et al. (2007) presented an evaluation of a haptic system to determine the benefits	23 students (13 female and 10 male) were divided into two groups and given a lesson on protein-ligand	There was no obvious advantage from adding force feedback to the lesson.
			haptics can have on biomolecular educational	docking.	Researchers reported that haptics did successfully convey the
			context.	The first group had haptic device turned on while the	importance of forces in understanding the biomolecular
			Biomolecular sciences make great use of visual	other group had haptic device turned off during	lesson (Persson et al., 2007).
			representations to convey abstract knowledge.	the experiment.	Qualitative statistical analysis of student interviews indicated that the
			Visual and haptic display	Researchers used cognitive knowledge tests and	use of haptic instruments helped some students understand the forces
			combination is frequently used in sciences for macro stuff.	interviews to assess any potential knowledge differences between the	involved and better comprehend the biomolecular models
			Use of force feedback can	two groups.	Future research: Persson et al.
			ease the understanding of variety of complex processes.	H1: does adding haptic improve learner understanding?	help students understand the subject matter and how do one's spatial abilities help the learner to navigate the 3D content.
			Haptics used offered object hardness, density and shape.		

Triona & Klahr	n=92 51 girl	Triona and Klahr (2003) compared two	92 4 th and 5th grade children were taught how	There was no significant statistical difference between the group who
(2003)	41 boys	instructional conditions that only differed in their delivery medium.	to design an uncounfounded experiments by using one of two instructional	interacted with the physical learning materials and the group that completed their work on the PC, as students in both treatments
		The first condition used physical springs and weights and the students	methods. To gather data for this experiment, researchers used three-	made large gains in knowledge (Triona and Klahr, 2003).
		were required to handle them, while the second condition was in the form of the software simulation of springs and weights.	phase factorial design: pre- test and training, post-test, and transfer to measure students learning (Triona and Klahr, 2003).	The authors suggest that replacing the physical materials with virtual materials does not affect the amount of learning transfer when aspects of the instruction are preserved (as they were in this
		Metaanalysis of tangible interfaces vs. pc software:		case)
		Bredderman, 1983; Shymansky, Kyle, & Alport, 1983; Sowell, 1989; Stohr-Hunt, 1996		Future research: Triona and Klahr (2003) point out that there are two issues that need to be addressed before one can state whether technology can influence learning: (a) Are there differential effects of media for different types of tasks; and (b) Would the computer have the same learning effect without a human instructor?

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APPENDIX E: MARKER TRAINING

Marker Training

1. Hold Marker 1 - L as pictured in Figure 1.



Figure 1. Proper way of holding the Marker 1

2. Position Marker 1 (Figure 2) so you can see the Earth aligned

with the New Moon and the Sun.


Figure 2. Earth aligned with the New Moon and the Sun.

APPENDIX F: ARTAT TREATMENT

Lunar Phases – Introduction

The Moon, Earth's only natural satellite and one of the brightest objects in its sky, appears in the sky in many different shapes. It is also the only place in our solar system, other than Earth, where humans have visited. The Earth's Moon is the fifth largest in the whole solar system, and is bigger than Pluto. The Moon has a nearly circular orbit which is tilted about 5° to the plane of the Earth's orbit. Its average distance from the Earth is 238,855 miles (384,400 km). The combination of the Moon's size and its distance from the Earth causes the Moon to appear the same size in the sky as the Sun, which is one reason we can have total solar eclipses.

It takes the Moon 27.3 days to go around the Earth once. **Pick up Marker 2** - \bigcirc to see this effect. The Moon orbits the Earth in a counter-clockwise motion and during one calendar year it makes around 13.4 of these rotations. Because of this motion, the Moon appears to move about 13° against the stars each day, or about one-half degree per hour. If you watch the Moon over the course of several hours one night, you will notice that its position among the stars will change by a few degrees. The changing position of the Moon with respect to the Sun leads to lunar phases.

Because the Moon is spherical and the hemisphere that faces the Sun reflects sunlight, half of the Moon is always illuminated. Depending on the Moon's position relative to Earth, different portions of this illuminated hemisphere are visible to us.

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Lunar Phases

The Moon travels around the Earth in an oval shaped orbit every 27.3 days. During this travel, the Moon goes through a cycle of phases or changes in its apparent shape as viewed from Earth. Because of the Earth's rotation, the Moon appears to rise in the east and set in the west each day. When viewed from Earth's North Pole, Earth and Moon rotate counter-clockwise about their axes; the Moon orbits Earth counter-clockwise and Earth orbits the Sun counter-clockwise (**Pick up Marker 2 to see this effect**).

Five designations that describe the Moon's apparent shape and sequence of phases are: new, crescent, quarter, gibbous, and full. Despite this division into five stages, the phases of the Moon are in fact part of a continuum. As the Moon orbits Earth, the portion of its illuminated hemisphere that is visible from Earth changes slightly every day.

First Quarter

During the New Moon phase, the Moon is between the Sun and Earth. Because of this placement, the Moon's illuminated half is facing away from Earth. Therefore, the Moon is not visible from the Earth. Pick up Marker 3 - 2 and line up observer on Earth's North Pole with the New Moon and the Sun to see this lunar phase. Additionally, the moon is up throughout the day, and down throughout the night. For these reasons we cannot see the Moon during this phase. New Moon generally occurs once a month.

As the Moon continues its orbit, the illuminated side gradually becomes visible and is seen as a crescent as seen in **Marker 3**. This phase is also referred to as **Waxing Crescent**. This lunar sliver can be seen each evening for a few minutes just after sunset. We say that the Moon is "waxing" because each night a little bit more is visible for a little bit longer. During this phase, the Moon begins to look like letter "D." **Pick up Marker 3** and line up the observer on the North Pole with Waxing Crescent Moon to see this lunar phase.

Over the next few days, the crescent appears to grow, or wax, showing a larger portion of the illuminated side of the Moon each successive day.

When half of its illuminated hemisphere becomes visible from Earth, the Moon appears as a half-disk, also known as the **First Quarter** Moon. **Pick up Marker 3 and line up the observer on the North Pole with the First Quarter Moon to see this lunar phase.** During first quarter, 1/2 of the Moon rises at noon and is high overhead at sunset (around 6pm). Thus it is visible for the first half of the evening, and then goes down around midnight, leaving the sky very dark.

Continue on next page →

Second Quarter

The Moon then continues to wax through gibbous phase, in which more than half of the illuminated side is visible from Earth. This phase is called **Waxing Gibbous**. Observers can see all but a little sliver of the moon. **Pick up Marker 4** - $\stackrel{\circ}{\clubsuit}$ and line up the observer on the North Pole with Waxing Gibbous Moon to see this lunar phase.

During this phase, the Moon remains in the sky most of the night. The Moon has moved in its orbit so that it's now relatively far from the Sun in our sky. A waxing gibbous Moon rises during the hours between noon and sunset. It sets in the wee hours after midnight and it is most visible around 9pm.

When the Moon reaches the point of its orbit at which it is on the opposite side of Earth from the Sun, the entire lit hemisphere is visible and it appears as a **Full Moon** — a complete circular disk. **Pick up Marker 4 and line up the observer on the North Pole with Full Moon to see this lunar phase.**

A full Moon will rise just as the evening begins, and will set about the time morning is ushered in. The best time for viewing it is around midnight. In many ways, a full moon is the opposite of a new Moon. At both the new and full phases, the moon is on a line with the Earth and Sun. At **New Moon**, the Moon is in the middle position along the line. At **Full Moon**, Earth is in the middle, between the Moon and the Sun.

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Third Quarter

As the Moon proceeds around the rest of its orbit, it wanes from full moon to **Waning Gibbous**. Like the Waxing Gibbous Moon, during this phase, we can see all but a sliver of the Moon. The difference is that instead of seeing more of the Moon each night, we begin to see less and less of the Moon each night. This is what the word "waning" means. During this phase the Moon begins to look like the letter "C." **Pick up Marker 5** - "2" and line up the observer on the North Pole with Waning Gibbous Moon to see this lunar phase

After **Waning Gibbous**, the next waning stage is called the **Last Quarter**. During a Last Quarter Moon we can see exactly 1/2 of the Moon's lighted surface. **Pick up Marker 5** and line up the observer on the North Pole with Last Quarter Moon to see this lunar phase. This phase rises around midnight, appears at its highest in the sky at dawn (around 6am), and sets around noon.

Last Quarter Moon comes about three weeks after New Moon. In Marker 5 we can observe that the Moon in its orbit around Earth is at right angles to a line between the Earth and Sun. The moon is now three-quarters of the way around in its orbit of Earth, as measured from one new Moon to the next.

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Fourth Quarter

Finally, during a **Waning Crescent**, or "**Old Moon**", observers on Earth can only see a small sliver of the Moon, and only just before morning. Each night less of the Moon is visible for less time. Now the Moon has moved nearly entirely around in its orbit of Earth, as measured from one new Moon to the next. **Pick up Marker 6** - $\overset{\circ}{\clubsuit}$ and line up the observer on the North Pole with Waning Crescent Moon to see this lunar phase.

Because the Moon is nearly on a line with the Earth and Sun again, the day hemisphere of the moon is facing mostly away from us once more. That is why we only see a slender fraction of the Moon's day side (**Waning Crescent Moon**).

Over time, gravitational forces between the Moon and Earth have synchronized the Moon's rotation rate with its orbit, such that the Moon takes 27.3 days both to orbit Earth and to rotate on its axis. As a result, the **same side of the Moon** always faces Earth, and from Earth's surface people never see the far side.

APPENDIX G: ITAT TREATMENT

Lunar Phases - Introduction

The Moon, Earth's only natural satellite and one of the brightest objects in its sky, appears in the sky in many different shapes. It is also the only place in our solar system, other than Earth, where humans have visited. The Earth's Moon is the fifth largest in the whole solar system, and is bigger than Pluto. The Moon has a nearly circular orbit which is tilted about 5° to the plane of the Earth's orbit. Its average distance from the Earth is 238,855 miles (384,400 km). The combination of the Moon's size and its distance from the Earth causes the Moon to appear the same size in the sky as the Sun, which is one reason we can have total solar eclipses.

It takes the Moon 27.3 days to go around the Earth once (**see Figure G1**). The Moon orbits the Earth in a counter-clockwise motion and during one calendar year it makes around 13.4 of these rotations (**Figure G1**). Because of this motion, the Moon appears to move about 13° against the stars each day, or about one-half degree per hour. If you watch the Moon over the course of several hours one night, you will notice that its position among the stars will change by a few degrees. The changing position of the Moon with respect to the Sun leads to lunar phases.





Because the Moon is spherical and the hemisphere that faces the Sun reflects sunlight, half of the Moon is always illuminated. Depending on the Moon's position relative to Earth, different portions of this illuminated hemisphere are visible to us.

Lunar Phases

The Moon travels around the Earth in an oval shaped orbit every 27.3 days. During this travel, the Moon goes through a cycle of phases or changes in its apparent shape as viewed from Earth. Because of the Earth's rotation, the Moon appears to rise in the east and set in the west each day. When viewed from Earth's North Pole, Earth and Moon rotate counter-clockwise about their axes; the Moon orbits Earth counter-clockwise and Earth orbits the Sun counter-clockwise (**Figure G1**).

Five designations that describe the Moon's apparent shape and sequence of phases are: new, crescent, quarter, gibbous, and full. Despite this division into five stages, the phases of the Moon are in fact part of a continuum. As the Moon orbits Earth, the portion of its illuminated hemisphere that is visible from Earth changes slightly every day.

First Quarter

During the **New Moon** phase (see Figure 2), the Moon is between the Sun and Earth. Because of this placement, the Moon's illuminated half is facing away from Earth. Therefore, the Moon is not visible from the Earth. Additionally, the moon is up throughout the day, and down throughout the night. For these reasons we cannot see the Moon during this phase. New Moon generally occurs once a month.

Figure G2 First Quarter



As the Moon continues its orbit, the illuminated side gradually becomes visible and is seen as a crescent as seen in **Figure 2**. This phase is also referred to as **Waxing Crescent**. This lunar sliver can be seen each evening for a few minutes just after sunset. We say that the Moon is "waxing" because each night a little bit more is visible for a little bit longer. During this phase, the Moon begins to look like letter "D."

Over the next few days, the crescent appears to grow, or wax, showing a larger portion of the illuminated side of the Moon each successive day.

When half of its illuminated hemisphere becomes visible from Earth, the Moon appears as a half-disk, also known as the **First Quarter** Moon (**see Figure 2**). During first quarter, 1/2 of the Moon rises at noon and is high overhead at sunset (around 6pm). Thus it is visible for the first half of the evening, and then goes down around midnight, leaving the sky very dark.

Second Quarter

The Moon then continues to wax through gibbous phase, in which more than half of the illuminated side is visible from Earth. This phase is called **Waxing Gibbous (Figure G3)**. Observers can see all but a little sliver of the moon. During this phase, the Moon remains in the sky most of the night. The Moon has moved in its orbit so that it's now relatively far from the Sun in our sky. A waxing gibbous Moon rises during the hours between noon and sunset. It sets in the wee hours after midnight and it is most visible around 9pm.



Figure G3 Second Quarter

When the Moon reaches the point of its orbit at which it is on the opposite side of Earth from the Sun, the entire lit hemisphere is visible and it appears as a **Full Moon** — a complete circular disk (**see Figure 3**). A full Moon will rise just as the evening begins, and will set about the time morning is ushered in. The best time for viewing it is around midnight. In many ways, a full moon is the opposite of a new Moon. At both the new and full phases, the moon is on a line with the Earth and Sun. At **New Moon**, the Moon is in the middle position along the line. At **Full Moon**, Earth is in the middle, between the Moon and the Sun.

Third Quarter

As the Moon proceeds around the rest of its orbit, it wanes from full moon to **Waning Gibbous** (**Figure G4**). Like the Waxing Gibbous Moon, during this phase, we can see all but a sliver of the Moon. The difference is that instead of seeing more of the Moon each night, we begin to see less and less of the Moon each night. This is what the word "waning" means. During this phase the Moon begins to look like the letter "C."





After Waning Gibbous, the next waning stage is called the Last Quarter (see Figure G4). During a Last Quarter Moon we can see exactly 1/2 of the Moon's lighted surface. This phase rises around midnight, appears at its highest in the sky at dawn (around 6am), and sets around noon.

Last Quarter Moon comes about three weeks after New Moon. In Figure 4 we can observe that the Moon in its orbit around Earth is at right angles to a line between the Earth and Sun. The moon is now three-quarters of the way around in its orbit of Earth, as measured from one new Moon to the next.

Fourth Quarter

Finally, during a **Waning Crescent**, or "**Old Moon**", observers on Earth can only see a small sliver of the Moon, and only just before morning (**see Figure G5**). Each night less of the Moon is visible for less time. Now the Moon has moved nearly entirely around in its orbit of Earth, as measured from one new Moon to the next.





Because the Moon is nearly on a line with the Earth and Sun again, the day hemisphere of the moon is facing mostly away from us once more. That is why we only see a slender fraction of the Moon's day side (**Waning Crescent Moon**).

Over time, gravitational forces between the Moon and Earth have synchronized the Moon's rotation rate with its orbit, such that the Moon takes 27.3 days both to orbit Earth and to rotate on its axis. As a result, the **same side of the Moon** always faces Earth, and from Earth's surface people never see the far side.

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Research Interests

Incorporation of technology into teaching and learning, emerging learning technologies

Augmented Reality, Human Computer Interaction

Community Service

Call me MISTER Leadership Academy mentor, 2013

EKU Diversity Conference promotional video, 2012

Boy Scouts of America promotional video, 2011

Past Board member, Bluegrass Cycling Club, 2011

Mean Represe

Nedim Slijepcevic

Signature of Student