The effect of Augmented Reality and Virtual Reality interfaces on Epistemic Actions and the Creative Process

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

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a candidate for the degree of doctor of philosophy and hereby certify that, in their opinion, it is worthy of acceptance.

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Abstract

The aim of the study is to investigate how VR and AR interfaces affect the creative design process in design education. Theories from cognitive psychology, information sciences, and design cognition are provide an explanatory mechanism to indicate that epistemic action reduces cognitive load, thereby reducing fixation in the design process and enhancing the creative design process.

Thirty undergraduate design students were randomly divided into two groups that used AR or VR to complete a simple project that required students to design the interior of an office. Mixed qualitative and quantitative methods were used. A linkography protocol was used to understand the effect of different interfaces on the creative design process and a questionnaire was administered to examine the effect of user characteristics on the creative design process. Results of the study indicated that AR interfaces tend to encourage more epistemic actions during the design process than the VR interfaces. Epistemic actions were found to reduce the cognitive load thereby reducing fixation in the creative design process. From calculating entropy of the design process, AR appeared to provide a more conducive environment for creativity than VR.

The second part of the study focuses on how individual characteristics of the students moderate the effect of technology traits in enhancing the creative design process. Learner preferences were analyzed through learning styles and technology acceptance was measured to understand how different learning styles affect technology acceptance of the two media types of AR and VR. The theoretical background suggests that perceived

ease of use correlates with creativity. Hence, learner preferences were hypothesized to affect the use of different types of media in the creative design process. The results did not indicate that learner preferences affected the creative design process but did support the conclusion that certain user preferences lead to higher acceptance levels for technology.

Preface

I have been fortunate to teach design at three tertiary education institutions. This study was inspired by my experience gained through teaching. Initially I was fascinated with the design process and how students designed in a design studio environment. I saw that sometimes the tools that students used were inefficient and at times even inhibited them in reproducing their visions of design, which made me wonder if there were other tools and methods that students could incorporate in their design process. My passion for digital media led me to think that different digital media tools might be helpful in enhancing the creative design process.

This study is a culmination of information and knowledge gained through multiple studies conducted over a 5-year period. The studies focused on the design process, intrinsic features of virtual (VR) and augmented reality (AR), and the effect of these technologies on design education.

Chandrasekera, Vo, and D'Souza (2013) observed the design process and identified episodes of high entropic value that they termed *sudden moments of inspiration* (SMI) or *A-Ha moments*. Their study used think-aloud protocol analysis, which is considered one of the best methods of analyzing the design process. Even though Chandrasekera et al. examined SMIs as episodes of higher entropic values, they also focused on fixation and how fixation affects the design process. Entropic values are considered as the amount of information included in the design process and fixation is considered as the process of following a limited set of ideas within the design process. In the current study the emphasis is on the design process and how fixation, which is considered inherently a low entropic episode, affects the design process.

Chandrasekera, Yoon, & D'Souza (2015) and Chandrasekera (2015) focused on inherent characteristics of VR and how certain types of VR can be used in design education. Chandrasekera et al. explored the applicability of using VR as a tool in environmental behavioral research. The objectives of their study were to eventually help assist designers and researchers who are interested in alternate navigational methods for virtual environments and to better understand how soundscapes can be used in creating navigational tools for virtual environments. In Chandrasekera (2015) the purpose was to develop the knowledge base to guide the planning and design of online virtual collaborative environments that can achieve effective learning outcomes through a design critique process by initiating a framework for online based design critiques. Both of these studies contributed knowledge about using VR as a tool in environmental behavior and design education.

Chandrasekera et al. (2012) and Chandrasekera and Yoon (2015) described how AR affects the design process and design education by improving spatial skills. In both of these studies the effectiveness of VR and AR were compared for design instruction purposes, and AR instruction modalities were hypothesized to improve spatial abilities of design students as compared with VR instruction modalities. Although these two studies presented a means of adopting AR in design instruction, the conclusions suggested that the differences between the two interfaces may have been due to the method of control provided by each interface.

Chandrasekera (2014) described a method of using AR prototypes in design education. The technology acceptance model was used to assess the students' perceived usefulness, perceived ease of use, and behavioral intention to use the technology. Even though Chandrasekera (2014) speculated that AR would be a potential tool to be used in design and design education because it may help alleviate fixation, he did not provide empirical evidence to support this claim. Investigating the potential of AR in reducing fixation was considered a future direction of the study.

Chandrasekera and Yoon (2014a) described a pilot of the current study using a smaller number of participants and found similar outcomes and conclusions as the current study. Similar to the current study, the main hypothesis of their study was that AR interfaces offer epistemic action that reduces the cognitive load and reduces fixation effects in the design process as compared with VR interfaces, thereby affecting the creative design process. Fixation was identified in both AR and VR interfaces. Observations from Chandrasekera and Yoon suggested that AR interfaces provide an environment that is conducive for the design process to be more productive. Identifying the differences in entropy levels and the stages in which entropy was high and low in both interfaces lead to the conclusion that interface type affects the creative design process.

The current study combines and makes inferences from the aforementioned studies. The current study describes the differences in using AR and VR in the design process by focusing on how the design process is affected by the characteristics of the technology as well as the characteristics of the user.

Chapter 1. Introduction

The use of digital tools in design education has dramatically increased. These tools have been commonly used as representational (Langenhan, Weber, Liwicki, Petzold, & Dengel, 2011; Marcos, 2011; Shelden, 2002), collaborative (Engeli & Mueller, 1999; Gül, 2011; Merrick & Gu, 2011), and communicative media (Chiu, 2002). Among the various digital tools, Virtual Reality (VR) has been popular for all three purposes (Frost & Warren, 2000; Whyte, 2003; Whyte, Bouchlaghem, Thorpe, & McCaffer, 2000). More recently, the use of Augmented Reality (AR) has increased as well (Fonseca, Villagrasa, Martí, Redondo, & Sánchez, 2013; Stouffs, Janssen, Roudavski & Tunçer, 2013; Wang, 2007).

While VR can be interpreted as immersive three-dimensional computer-generated environments (Bryson, 1995), AR can be conceptualized as overlaying virtual objects over the physical environment (Fischer et al., 2006). Researchers have investigated how AR and VR can be used in design and design education, but there is a gap in knowledge about how these interfaces affect the cognitive process of designing. Interfaces such as AR that allow interaction with digital information through the physical environment, also referred to as tangible interaction (Ishii & Ullmer, 1997), allow more epistemic action (Fitzmaurice, 1996). Epistemic actions, defined as exploratory or trial-and-error type of actions (Kirsh & Maglio, 1994), enable a designer to manipulate the design freely, reducing the cognitive load and conserving mental effort. Researchers have suggested that the reduction in cognitive load reduces fixation effects (Kershaw, Hölttä-Otto, & Lee, 2011; Moreno, Yang, Hernandez, & Wood, 2014; Youmans, 2007). Research suggests that by reducing cognitive demand, cognitive resources can be used for other activities, which allows moving away from a linear thought process, and reduce fixation effects. Design fixation is often associated with negative effects on the design process primarily during the design incubation and ideation stages (Moreno, Yang, Hernandez, Linsey, & Wood, 2014). Reducing cognitive load has been shown to reduce fixation effects in the design process (Chandrasekera & Yoon, 2014a; Youmans, 2011).

A few researchers have explored the differences between AR and VR. Milgram and Kishino (1994) described the virtuality-reality continuum to compare and discuss the digital interface within a continuum. Tang, Biocca, and Lim (2004) discussed the differences between the two interfaces in more detail by considering technology traits of the two types of media. However, few studies have specifically focused on these two interfaces and analyzed how their traits affect the creative design process and design education. The current study looks at how these two types of media affect epistemic action, thereby affecting the cognitive load and fixation in the design process.

This study also examines how user characteristics affect the use of AR and VR. Specifically, the user characteristic of learner preference using the VARK Learning Styles Inventory was examined to test the hypothesis that learner preference correlates to the acceptance of that particular technology, thereby affecting the creative design process through intrinsic motivation.

Factors Affecting the Design Process

The process of designing is a complex problem-solving exercise. Some authors suggest that design is more a process of problem framing (Gao & Kvan, 2004) than of problem solving. Archea (1987) refers to the design process as puzzle-making, and design is often described as a wicked problem (Buchanan, 1992; Rittel & Webber, 1984) or an ill-defined/structured problem (Simon, 1973). The design process can also be seen as a method of problem management in which the required function is fulfilled even though an optimal solution is not realized.

The problem-solving process has been discussed extensively in a number of studies (Ackoff, 1974; Broadbent, 1973; Lawson, 1983). Design problem solving has been analyzed and explained using methods such as insight problem solving (Chandrasekera, Vo, & D'Souza, 2013), trial and error problem solving (Youmans, 2011), and formal and logical processes (Dorst, 2011). The effect of prototyping (which is essentially a trial and error method of problem solving) is discussed in a number of studies with regard to design problem solving (Kershaw et al., 2011; Youmans, 2011; Viswanathan, & Linsey, 2009). In most studies in which prototyping in the design process is discussed, one recurring theme is its effect on fixation (Chandrasekera, 2014; Viswanathan & Linsey, 2009; Youmans, 2011).

Gestalt psychologists have extensively studied mental blocks as a phenomenon interchangeable with fixation found in design studies (Murty & Purcell, 2003). While a mental block is defined as "a barrier in our minds preventing us from producing desired information" (Kozak, Sternglanz, Viswanathan, & Wegner, 2008, p. 1123) design fixation is described as the inability of the designer to move away from an idea in order to resolve a problem (Jansson & Smith, 1991). Fixation is often identified as a process that interferes with creative reasoning and leads one to become fixated on a small number of unvaried solutions (Agogue & Cassotti, 2013). Fixation can become a hindrance in the creative design problem solving process. Potential solutions to mitigate fixation effects in the design process have been explored in previous studies, including encouraging group work (Youmans, 2011) and introducing analogical inspiration sources (Casakin & Goldschmidt, 1999). Even though in some instances prototyping has been identified as a method of reducing fixation (Dow et al., 2010; Youmans, 2011), in other studies physical prototyping increased fixation (Christensen & Schunn, 2007). Researchers have explained the fixation caused through physical prototyping as a result of sunk-cost effect: the time designers spend making the physical prototype of their initial ideas is when they tend to fixate more (Viswanathan & Linsey, 2013). Digital prototyping can be considered an approach to alleviate fixation effects caused by physical prototyping because digital prototyping is a way of bypassing the sunk-cost effect.

AR is an interface that offers tangible interaction (Ishii, 2007) and is often referred to as tangible user interface (TUI). Kim and Maher (2008) suggested that digital prototyping using TUIs such as AR allowed users to make additional inferences from visio-spatial features, freeing designers from fixation effects. Kim and Maher stated that tangibility in these types of interfaces allows more opportunities for trial and error type of problem solving through epistemic actions in prototyping.

Kirsh and Maglio (1994) introduced the concepts of epistemic action and pragmatic action. They discussed how expert players of the popular video game Tetris conserve their cognitive resources by trying different positions of the Tetris cubes rather than trying to figure it out in their minds. These experimental moves, which they termed epistemic actions, allow the players to use their cognitive resources for something else. Fitzmaurice (1996) used the same terms in discussing tangibility in user interfaces. He introduced the concept of graspable user interface (similar to TUI) and suggested that the tangibility in interfaces such as AR interfaces allows more epistemic action, thereby reducing the cognitive load and conserving mental effort.

Others (Kershaw et al, 2011; Moreno et al., 2014; Youmans, 2007) suggested that when cognitive load is reduced the fixation effects in design are reduced as well because epistemic actions allow a designer to manipulate the design freely. At the same time this reduction in cognitive load allows the designer to avoid fixation. This does not imply that fixation can be eliminated by allowing epistemic action alone, but merely that epistemic action reduces fixation effects. However, studies have shown that fixation adversely affects the creative process (Kohn & Smith, 2009; Smith & Blankenship, 1989, 1991), so it is important to investigate whether epistemic actions could reduce cognitive load and thereby reduce the chances of fixation and positively affect the creative design process (see Figure 1).

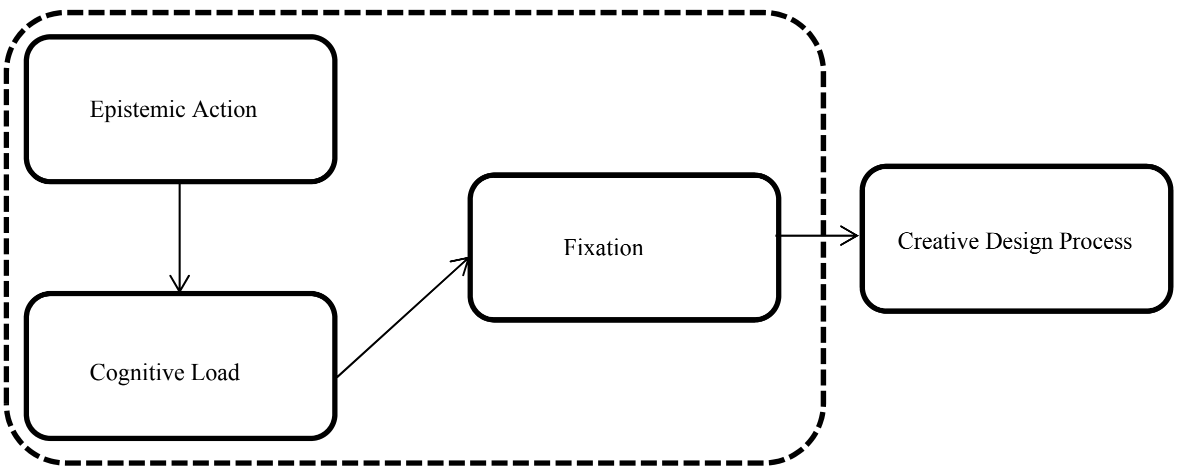


Figure 1. Effect of epistemic action and cognitive load on the creative design process.

Individuals use interfaces in different ways for different purposes. Research has shown that user characteristics such as preference for using an interface can result in effective use of the interface. Factors such as cognitive style, gender, and preference have been shown to impact creativity and the ideation process (Baer, 1997; Baer & Kaufman, 2008; Lubart, 1999; Pearsall, Ellis, & Evans, 2008; Shalley, Zhou, & Oldham, 2004; Wolfradt & Pretz, 2001). Furthermore, there is a relationship between learner preference and creativity (Atkinson, 2004; Eishani, Saa'd, & Nami, 2014; Friedel & Rudd, 2006; Kassim, 2013; Ogot & Okudan, 2007; Tsai & Shirley, 2013). The purpose of this study is to explore how user characteristics (i.e. learner preference) affect the use of AR and VR in the creative design process.

The VARK Learning Styles inventory was used to measure learner preferences for visual, auditory, read/write, and kinesthetic learning styles. The VARK is considered to be a valid learner preferences tool and it has been used by many researchers (Bell, Koch, & Green, 2014;Drago, & Wagner, 2004; Lau, Yuen, & Chan, 2015). It was used in this study because it focuses on kinesthetic and visual learning styles, which relate to the characteristics of the interfaces that are investigated in this study. The hypothesis was that learners with a preference for kinesthetic learning will prefer to use an interface that provides more tactility, while those who have a preference for visual learning will prefer to use an interface that provides more visual cues.

Learning styles are thought of as a user's preference for using a certain modality as a means to learn. The hypothesis of the study was that the learner preference correlates to the acceptance of that particular technology, thereby affecting the creative design process through intrinsic motivation (see Figure 2).

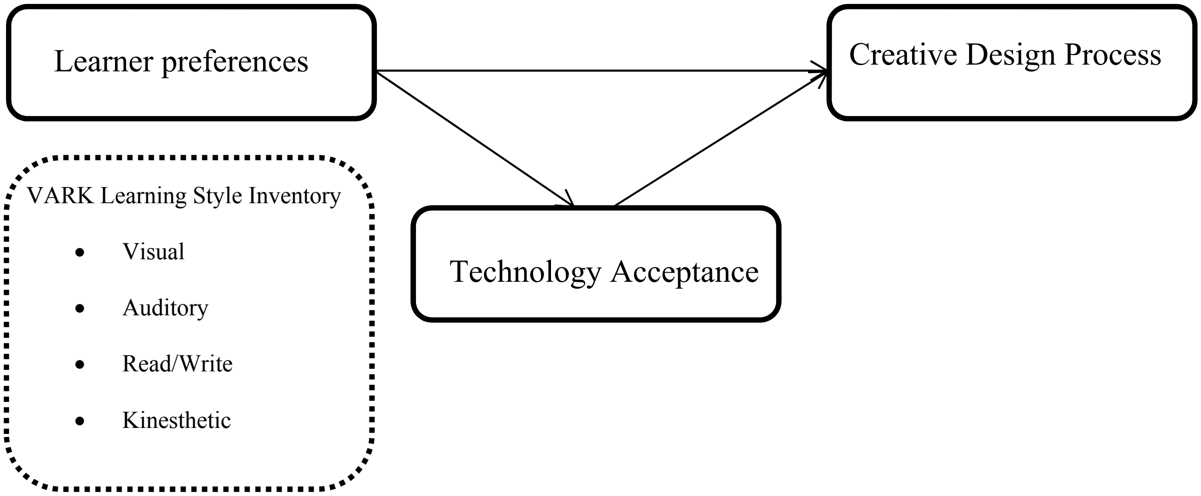


Figure 2. Effect of learner preferences on using AR and VR in the creative design process.

Understanding how AR and VR provide opportunities for epistemic actions and how these epistemic actions affect the creative design process is the primary focus of this study. Furthermore, since the study focuses on the use of these interfaces in the context of design education, the focus is appropriately on user characteristics such as learner preferences and observing how these preferences affect the use of these technologies in the creative design process.

Purpose of the Study

The context of this investigation is design education. The main objective of this study is to examine the effects of using AR and VR digital interfaces in design and design education. In particular, the study is focused on how these interfaces provide epistemic actions that affect the creative design process. The study also focuses on learner preferences and how learner preference affects the use of these technologies in the creative design process.

Even though AR has existed for several decades, there is a gap in the knowledge about how human factors affect the use of AR (Huang, Alem, & Livingston, 2012). Better understanding of user experience factors in AR environments is important for a number of reasons. With the emergence of new hardware that has the capability of supporting AR applications, interest in how to use this technology efficiently has been increasing. Such studies are only currently becoming feasible because of the recent maturation of the technology. Extensive studies of this type will allow the development of specific and general design and usage guidelines for AR technology not only in design education and design practice but in other fields of study as well. Moreover, understanding human perception of AR will accelerate the introduction of such technologies into mainstream use beyond the current novelty value of AR.

The results of this study provide a better understanding of how users are affected by such interfaces and can be used to formulate a comprehensive structured pedagogical agenda for digital design. Additionally, knowledge gained through this exercise can be applied to design education and design practice in order to promote creativity in the design process.

Research Contributions and Significance of the Study

The research provides a starting ground for discussing how user interfaces affect the design process. Factors such as cognitive load and fixation are discussed as a result of affordances in epistemic action. Given the current pace of technological innovation (in terms of hardware as well as software), identifying an interface type that affords better design ideation has become a critical need, and this research aims at fulfilling this need.

The contributions of the current study can be broadly categorized as theoretical, methodological, and practical.

Although prior research has produced a body of knowledge that focuses on using technologies such as AR and VR in various domains, few studies have focused on empirical evidence for enhancing the design process by using AR and VR in design and design education. More specifically, few studies focus on how these types of media provide opportunities for epistemic actions that reduce cognitive load and thereby reduce fixation effects in order to enhance the creative design process. Most researchers who have explored these traits have looked at them in isolation and not as a continuous process. This study bridges the gap in knowledge by combining theories adopted from information theory, design theory, and cognitive psychology to empirically understand the effect of tangibility in interfaces such as AR and VR on the creative design process.

Few studies have focused on cognitive load in the realm of design and design education. The current study focuses on understanding the theoretical connections between cognitive load and interface type by bridging theories of cognitive psychology, information science, and design cognition theory.

The knowledge obtained in this study can contribute to multiple domains with practical insights about using different interface types in the design process. The theoretical links established in this study set a framework for future research specifically in the domain of design education and AR and are also expected to affect research conducted in the paradigm of tangible interface design.

This study contributes to methodology in the use of AR and VR technology for design education as well as the use of linkography to analyze design protocols. Even though technologies such as AR and VR have existed for over a half a decade, their use in empirical research has been limited because of the cost associated with the hardware and software for such technologies.

However, with the advent of new technologies and their adoption in design education, understanding why and how these technologies can be used is important. This study provides empirical evidence about the use of AR in design and design education as well as a cost-effective method of using AR and VR in design research. The methodology adopted in this study may be used by other researchers for the purpose of obtaining cost-effective AR and VR solutions.

Even though protocol analysis is a popular method in analyzing the design process, linkography in protocol analysis is not common. This study incorporates a linkography method together with quantitative analysis methods to understand the impact of media interfaces on the creative design process. This study methodology can be replicated and used to understand the effect of other types of media on the creative design process.

The results of the study have implications for practical application of AR and VR in design and design education. Instructional design focuses on cognitive load and its implication for the learning outcome of students. The current study also looks at the cognitive load imposed by AR and VR; hence, it also provides validation for using AR and VR in other areas of learning. Furthermore, the results of the study should contribute towards the development and use of tangibility in interfaces and its application in other domains.

Research Approach and Methodology

Two design problem-solving interfaces were employed: an AR interface and a VR interface. Both interfaces used a tabletop webcam and fiducial marker-based system. Thirty design students from a Midwestern university in the US were randomly assigned to the two interface environments.

The design problem was formulated in consideration of three main factors. The first was to provide a simple problem which would encourage the participants to focus on object manipulation, spatial and logical iterations, context, and user-behavior issues, while also keeping in mind visual appeal, composition, environmental considerations, and ergonomic factors. The second consideration was to formulate a design project that would allow the researcher to clearly identify epistemic actions. The selected design problem was to arrange furniture within an office space; the selected interfaces of AR and VR provided the ability to move and rotate these furniture pieces. The movement of these pieces of furniture would allow clear coding for epistemic actions. The third consideration was previous studies that were conducted for a similar purpose. These three considerations are further elaborated in the methods section.

In the current study, the participants were provided with a design problem for arranging furniture in an office room setting. The design processes of 10 randomly selected participants were then recorded, coded, and analyzed through a protocol analysis method that used linkography. All 30 participants responded to two questionnaires based on the technology acceptance model (post-test) and the VARK learning styles inventory (pre-test) to better understand how the interface affects the design process and human perception. The participants also completed the NASA Task Load indeX (TLX) questionnaire (post-test) in order to identify the cognitive load associated with the interface.

In summary, the following experiment was designed to test the effect of digital interfaces (AR and VR) on enhancing the creative design process by reducing fixation effects. Tangibility in user interfaces such as AR was predicted to contain fewer fixation features than design processes taking place using graphic-based interfaces such as VR. Furthermore, the learner preferences of the user were predicted to affect the use of the interface, ultimately affecting the creative design process.

Definition of Terms

Augmented Reality (AR). Azuma (1997) defined AR as a variation of VR technology that supplements reality by superimposing virtual objects into it. AR is an interface that allows tangible interaction through the use of fiducial markers. This is also termed "desktop augmented reality" in the literature. In this study, fiducial marker-based AR is used with a webcam.

Cognitive Load / Mental Workload. Cognitive load may be viewed as the level of mental effort required to process a given amount of information (Cooper, 1990). In this study, the perceived workload is considered the cognitive load imposed by the interface.

Creative Design Process. Creativity has been defined in many ways. In this study, the focus is on the creative process, more than on the creative end product. The creative process embraces both integration and diversification of ideas (Kan, Bilda, &

Gero, 2007) and through a productivity aspect creativity is defined as making new combinations of associative elements which are useful (Poincare ,1913)

Entropy. Entropy is defined as a measurement of the amount of information in the text of the protocol (Shannon, 1948). Gero (2011) used the calculated dynamic entropy of a linkograph to measure the fixation in a design process. In this study, the same method is used to observe the creative design process.

Epistemic Action. Epistemic action is defined as "exploratory" motor activity to uncover information that is hard to compute mentally (Kim & Maher, 2008). The term "epistemic action" refers to trial-and-error types of exploratory actions in this study.

Fixation. Design fixation refers to the process of following a limited set of ideas within the design process (Jansson & Smith, 1991). When the ideation process revolves around a single idea, the designer is thought to be fixated on this idea.

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).

Learning Style. There are many types of learning styles. In this study, learning style refers to the mode of learner preference of the student, such as Visual, Aural, Read/write, and Kinesthetic modes. An appropriate learning style inventory (i.e., the VARK Learning Style Inventory) is used to identify learning style.

Linkography. Linkography is a method used to understand the links between segments or moves in a protocol. Related segments or moves are linked together to form a graph that shows the links among different segments or moves.

Protocol Analysis. In this study, think-aloud protocol analysis is used. The designer is expected to verbalize his/her thoughts when designing. These verbalizations are recorded, coded, and analyzed.

Segments and Moves. A segment, whether consisting of one sentence or many, is defined as one coherent statement about a single item/space/topic (Suwa & Tversky, 1997, p. 391). A design move is "an act of reasoning which presents a coherent proposition pertaining to an entity that is being designed," and arguments are "the smallest sensible statements which go into the making of a move" (Goldschmidt, 1991, p. 125). According to Suwa and Tversky (1997), a segment corresponds to a design move in its granularity. In this study, the idea of a move is used to understand the protocol.

Virtual Reality (VR). VR is an artificial environment provided by a computer that is experienced through sensory stimuli such as visual or auditory stimuli and in which one's actions partially determine what happens in the environment (Virtual Reality, 2012). In this study, VR is identified as a windows, icons, menus, pointers (WIMP)-based computer-simulated 3D environment experienced through a computer monitor and interacted with through a control device such as a mouse. This is also termed "desktop virtual reality" in the literature.

Chapter 2. Literature Review

Creative Design Process

In most of the studies that have been conducted on design and the design process, the evolution of the design process was discussed as a step by step process, but the steps prior to sketching are neglected. How does an architect begin to design? Does the architect begin with arbitrary sketching? Lawson (1972) provided two contrasting styles of operation: problem focused and solution focused. He stated that in solving design problems, science students use a problem focus, which is much more analytical, while architecture students use a solution focused approach in which they try out different solutions and see what goes wrong. Hiller, Musgrove, and O'Sullivan (1972) provided a conjecture-analysis model for the design process and stated that in order to make a problem tractable it should be pre-structured, either explicitly or implicitly. Hiller et al. further stated that design is essentially a matter of pre-structuring problems and argued that this is the reason that design is resistant to empirical rationality. Even with a complete account of the designer's operations, gaps will still be apparent about the origin of the solution. Understanding how a designer designs is important to understand the role of creativity in the design process.

Dorst and Cross (2001) stated that creativity in the design process is often characterized by the occurrence of a significant event. This event may manifest itself as a sudden moment of inspiration (Chandrasekera et al., 2013), an increase in information (Kan, Bilda, & Gero, 2007), or a rapid change of ideas (Goldschmidt, 1995). Researchers have used protocol analysis methods to capture these creative moments in the design process. Dorst and Cross further stated that creativity is found in every design project, and many researchers have focused on identifying these creative moments.

Creativity

The term "creativity" has been used – or more precisely misused – especially in the context of design and design education. Despite Torrance's (1988, p. 43) statement that "creativity defies precise definition," many definitions of creativity have been provided. Discussions and commentaries on creativity suggest that the definitions provided may be categorized into multiple groups. Rhodes (1961) theorized that creativity falls into four distinct categories: individual aspects (the individual who is involved in the creative process), cognitive aspects (the creative process), the influence of the context where the creative process is taking place (place), and the resulting creative product. These are known as the four P's of creativity (person, process, place/press, and product).

As suggested by Rhodes (1961) creativity can be primarily discussed either in terms of the product or in terms of the process (Rosenman & Gero, 1993). Rosenman and Gero stated that a product can be considered to be the result of a creative process depending on the innovativeness of the product and the value and richness of interpretation and that the creativity of the process can be described from an information processing standpoint. They discussed the creative aspects of the creative process through entropy, efficiency, and richness. In some instances, creativity has been simply defined as the ability to look at things differently (Keil, 1987) or as an act that produces effective surprise (Brunder, 1962). The aspect of novelty has been central to a number of definitions of creativity (Morgan, 1953). Hausman (1964) stated that "each appearance of genuine novelty is a sign of creative activity" (p. 20). However these definitions of creativity and its connection with novelty have been much debated. Poincare (1913) deviated from the discussions of novelty and originality and focused on the productive aspects of creativity: "to create consists of making new combinations of associative elements which are useful" (p. 25).

Gero and Maher (2013) focused on the creative design process and stated that creativity introduces new variables to the design process which were not originally considered by the designer or design system; design and creative design are different because reasoning plays a major role in creative design. The term "design creativity" has been widely used (Daley, 1982; Goldschmidt & Tatsa, 2005; Taura & Nagai, 2010). While the Vitruvian virtues of architecture (Bredeson, 2002) are *utilitas* (function), *firmitas* (solidity/stability), and *venustas* (delight/aesthetics), design seldom stops at aesthetics; it goes beyond mere aesthetics and becomes an artifact that makes people think: from aesthetics to mindfulness. Taking this into consideration, design creativity cannot only focus on novelty but must also focus on utility and value (Gero & Maher, 2013).

Different phases in the creative process have been examined. Csikszentmihalyi (2006) stated that the creative process may include distinct phases that draw on different psychological resources**.** Some of the common phases provided in different models of the creative processes are summarized in Wallas's (1926) creativity phase model. This model originally consisted of seven steps that are discussed through the four phases of preparation, incubation, illumination, and verification. These phases of creativity become especially important in understanding where creative leaps in the creative process occur. This creative leap in the design process is identified by measuring the entropy of the process (Gero & Kazakov, 2001; Kan, Bilda, & Gero, 2007; Kan & Gero, 2005).

Creativity has been defined as an intersection of three psychological attributes: intelligence, cognitive style, and motivation (Sternberg, 1998). In her model of creativity, Amabile (1983) linked creativity with domain-relevant skills, creativity-relevant skills, and task motivation, stating that without any one of these, creativity cannot exist. In his multiple intelligence theory, Gardner (1983) takes a different approach to creativity and observes multiple components that affect creativity and the creative process: "the creative individual is a person who regularly solves problems, fashions products, or defines new questions in a domain in a way that is initially considered novel but that ultimately becomes accepted in a particular cultural setting" (p. 35). Csikszentmihalyi (1997) discussed creativity on a broader scale: creativity is the cultural equivalent of the process of genetic changes that result in biological evolution and the process by which a symbolic domain in the culture is changed. Furthermore, a number of studies suggest that multiple components must converge for creativity to occur (Amabile, 1983; Gruber, 1989; Perkins, 1984).

A challenge in creative design is to visualize alternate idea paths that are known as divergent thinking processes. For various reasons, divergent thinking in creative design gets inhibited and the process tends to take a linear path, which is termed "fixation." Fixation discourages creative design solutions because it inhibits alternate solutions to a design problem.

Defining Creativity in Context

Identifying where and when creativity occurs is important in understanding how creativity is enhanced or inhibited. Creativity assessments have included many factors such as novelty, originality, utility value, and aesthetics. Creativity measurements may be categorized according to the four p's of creativity: person, process, press/place and product.

The most widely accepted measurement of creativity, the Torrance Test of Creative Thinking, focuses on the individual's creative aptitude and uses verbal and figural tests to assess creativity (Torrance, 1966). Similarly, Guilford's (1968) model of measuring creativity focuses on the individual's creative aspects through looking at divergent and convergent thinking to assess fluency, flexibility, originality, and elaboration of ideas. Csikszentmihalyi and Getzels (1971) suggested that creativity should be measured by observing the individual, the area, or the domain that the person works in, and the people who engage with the work; creativity occurs when the person generates the creative product and the respective domain changes as a result of the product.

Creativity assessments in design and design education are often seen as a means of assessing the design product, the design process, or both. Researchers have emphasized the importance of assessing creativity in the design process as opposed to assessing creativity in the design product. McAllister (2010) stated that design students focus more attention on the end product and ignore the development process of the design. Furthermore, Bashier (2014) stated that design instruction has become problematic because instruction often tends to focus on the design product rather than the creative design process. To assess the creative product, researchers have employed several characteristics such as fluency, flexibility, elaboration, usefulness, innovation, fulfilling goals and design requirements, considering the physical context, mastery of skills, overall creativity, and alternative design solutions (Casakin & Kreitler, 2010). In design education, students are encouraged to present their design process in the form of diagrams and sketches in order for the jurors to evaluate the creative aspects of the final product.

One method of empirically measuring the design process makes use of the concept of entropy. Shanon (1948) defined entropy as a measurement of the amount of information in in a communication source such as text of a protocol. Kan and Gero (2005) used this idea in the context of the design process to identify the entropy in a design protocol. They stated that a higher entropy level suggests a more creative design process. Furthermore, they defined fixation as the reduction in entropy within the design process.

Fixation

Different types of fixation identified by researchers include problem solving fixation, conceptual fixation, cognitive fixation, knowledge fixation, operational fixation, and design fixation (Moreno, Yang, Hernández, Linsey, & Wood, 2014). Design fixation refers to the process of following of a limited set of ideas within the design process (Jansson & Smith, 1991). Jansson and Smith suggested that design fixation is limiting, can be counterproductive, and can lead to many barriers during the design process. They showed that designers who were given an example before initiating a new design were more likely to imitate the example. On the other hand, designers who were not shown an example were more likely to come up with something more original. Fixation is often shown to occur when using an example to inspire a new design, and the designer is usually unaware of his or her fixation (Toh, Miller, & Kremer, 2012).

Studies have shown that while in the creative process, people are more likely to run into obstacles when new solutions are not explored. This is known as the fixation effect (Agogué, Poirel, Pineau, Houdé, & Cassotti, 2014). A number of studies have explored reasons for fixation in the design process. Some researchers suggested that the designer's experience plays a major role in how fixation affects the design process (Linsey et al., 2010). Studies have also shown that the designer's personality type (Toh et al., 2012) and inclination towards existing solutions also affect the occurrence of fixation in the design process (Luchins & Luchins, 1959).

The study of fixation is not new to the field of design (Murty & Purcell; 2003; Purcell & Gero, 1996; Sachs, 1999). Purcell and Gero in Cross (2001b) discussed how specific education practices between designers and engineers could impact the way in which fixation occurs. For designers specifically, this type of fixation focuses on the notion of being "innovative" or "different."

Prototyping was shown to be an integral part of the design process in a series of experiments by Kershaw et al. (2011) in which students try to combat design fixation using two different methods: prototyping and critical feedback. In the first experiment, the prototyping method was administered to 50 non-engineering undergraduate students. The students were divided into groups and asked to design and construct a structure to solve a specific problem. The students were told to make a prototype before they built the final structure. They were given materials to sketch with, followed by materials to build their prototypes, and the session ended with feedback from instructors. After the first feedback session, students were allowed to modify their design, followed by a second feedback session. After the second feedback session, the majority made no changes to the design, some changed their design but only a very few chose to come up with an entirely new concept. There were students who completely ignored the feedback. The results of this study show how strong design fixation is based on the number of changes made after feedback was given.

The second experiment conducted by Kershaw et al. (2011) used the same design problem and creative process with 29 non-engineering undergraduate students. The difference in this experiment was the type of feedback given. Participants only drew sketches of their design instead of making prototypes and were split into different feedback groups. Those in the "no feedback" group were dismissed after they finished the final build of their design, and were not given any feedback upon completion. Participants in the "technical feedback" group followed the same method that was used in the first experiment. The final group, labeled "full critique," was given the same technical feedback as in the first experiment and was then asked a series of questions in order to encourage reflection about their design. After the first feedback session, majority of the students made changes to the design. Some came up with a new concept and a very few of them informed the feedback. When broken down among feedback groups, majority of the participants in the "no feedback" group came up with a new concept after feedback sessions; about half that number of the "technical feedback" group made a new concept, and no one in the "full critique" group made a new concept.

The researchers concluded for both groups that prototyping before building the final design helped to make changes necessary for improvement to the design. Participants in the second experiment who did not prototype their designs before building their finished products seemed to run into more problems than those in experiment 1.

Students of design, in particular, commonly have problems with design fixation as a premature commitment to a solution for a problem (Purcell & Gero, 1996). However, though problems are common, innovative and creative solutions can always be achieved. To overcome design fixation, analogical operators as well as instructions can be given to those who are learning the design process in addition to an example to be followed (Toh et al., 2012). Another method proposed by Toh et al. to reduce design fixation is called product dissection. Product dissection is the process of taking apart components and subcomponents of a product in order to analyze its structure and function and understand more about it. This opens opportunities for re-design by finding ways to improve the product. This is an important way for design students to learn what goes on in their future job industries and gives them a chance to take a hands-on approach to re-constructing products, as it allows for an in-depth look at the design from the ground up.

Feedback is a large component of design education as well. Kershaw et al. (2011) found that students who received more extensive feedback made fewer changes to their designs. They found this surprising, as they had thought that providing a group with detailed feedback would de-emphasize design fixation. One explanation was the possibility that students may feel more validated in their original designs when feedback is given, whereas the students who receive no or less feedback are forced to self-reflect and are more likely to make changes.

While many methods have been proposed to reduce the effect of fixation in the design process, it is important to note that prototyping has been shown to affect fixation (Christiansen & Schunn, 2007; 2009). Given that prototyping is an integral part of design and design education, a means to alleviate fixation effects in design prototyping is pertinent. While prototyping is broadly defined as a representation of a design idea before the final artifact exists (Lim, Stolterman & Tenenberg, 2008), various methods of prototyping have been introduced in the field of design. To eliminate the sunk-cost effect in physical prototyping, which can cause fixation, alternate methods of prototyping using digital interfaces are often used in design and design education. However, to further reduce fixation when using digital interfaces, understanding how fixation occurs in the design process is essential.

Identifying and Measuring Fixation

A number of studies have identified fixation using different methods. To identify functional fixedness (restricting the use of an object for a previously known function), Maier (1931) provided a problem-solving exercise that required participants to use pliers for something other than the typical use. Luchins and Luchins (1959) described another type of fixation called mental set, which referred to blindly being fixated on one solution. Jansson and Smith (1991) assessed fixation by providing their participants with an example solution to observe if the example affected the problem-solving process. The results suggested that providing such examples induced fixation. Chandrasekera et al. (2013) observed fixation occurring because of subliminal stimulation. They stated that subliminal stimulation not only was able to cause fixation but also affected the generation of sudden moments of inspiration (sudden moments of insight or A-Ha moments) in the creative design process. In a series of academic papers, Gero and associates (Gero & Kazakov, 2001; Kan et al., 2007; Kan & Gero, 2005; Purcell & Gero, 1996; Purcell, Williams, Gero, & Colbron, 1993) discussed fixation and methods of identifying fixation, specifically describing how they calculated entropy values in the design process to identify low and high values of entropy. They showed that low entropy values suggest fixation in the design process. Unlike other observational techniques in identifying fixation, the method proposed by Gero and associates provides an empirical means of measuring and identifying fixation.

Epistemic Action

Kirsh and Maglio (1994) defined epistemic actions as physical, external actions "that make mental computation easier, faster, or more reliable" (p. 513-514) or that are intended to gather more information (Kastens, Liben, & Agrawal, 2008). The term epistemic action, according to Kirsh and Maglio, is used to "designate a physical action whose primary function is to improve cognition" (1994, p 514). Kirsh and Maglio (1994) explained that this can be achieved by decreasing the memory involved in mental computation, the number of steps involved in mental computation, and the likelihood of error of mental computation. Epistemic actions differ from pragmatic actions, which have the primary function of bringing an individual closer to a physical goal. Similar terms were provided by Gibson (1962) who classified hand movements as "exploratory" and "performatory."

Kim and Maher (2008) expand on Gibsons classification and defined epistemic actions as "exploratory" motor activity to uncover information that is hard to compute mentally. They further elaborated that pragmatic actions refer to “performatory” and goal-oriented motor activity that directs the user closer to the final goal.

Kirsh and Maglio (1994) explained epistemic action using the example of the popular video game Tetris. The objective of Tetris is to complete full solid lines using the bricks, or “zoids” that manifest within the game. If the lines reach to the top, the player loses the game. While a novice player would mentally rotate the zoids in the game before moving them to create a single row of bricks, an expert player would manipulate the controls to rotate the zoid and then move the brick to the bottom layer to form a row of bricks. These manipulations of the controls (without exerting mental resources) were identified as epistemic actions.

The epistemic action hypothesis indicates that experts use tools more efficiently than beginners do because experts take more physical actions that simplify or improve mental computation (Maglio, Wenger, & Copeland, 2008). Maglio et al. showed that Tetris players with more experience could more effectively and quickly place blocks where they were supposed to go and more easily see the falling pieces in multiple orientations than beginners.

Epistemic actions are often referred to as trial-and-error type actions (Sharlin, Watson, Kitamura, Kishino, & Itoh, 2004) or exploratory motor activity. Trial-and-error type of actions are considered to improve the creative design process and are the norm in studio design education. Epistemic action in education involves hands-on projects, where students will operate and control physical objects while using deep thinking skills (Kastens, Agrawal, & Liben, 2008). Kastens et al. investigated how students and professionals collected and recorded spatial information and then used that information to form a mental model of a structure. They noted that most of their participants found their assigned tasks difficult, and some inquired if they were allowed to move their models around, showing examples of epistemic action.

Kim and Maher (2005) compared designers using GUIs and TUIs to arrange furniture within a 3D space and observed more epistemic actions in the environments where designers used a TUI such as an AR interface as compared to the environments in which designers used a GUI. Building upon Kim and Maher's (2005) findings, Fjeld and Barendregt (2009) compared epistemic action in a graphical user interface (GUI), tangible user interface (TUI), and physical modelling. They employed CAD software called Modeler as the graphics-based GUI, an AR application called Build-It as the tangibility-based TUI, and physical manipulation of blocks to solve a series of spatial problems. They measured epistemic action by observing the average number of tested blocks. While finding of both these studies attempt at making connections to cognitive load and the creative design process by discussing the changes in epistemic actions, they do not show direct connections not do they measure cognitive load and creativity in the design process.

Identifying and Measuring Epistemic Action

Epistemic actions are often associated with the idea of tangibility or the physical properties of an object or interface. Sharlin et al. (2004) stated that "a good physical tool enables users to perform pragmatic, goal-oriented activity as well as trial-and-error activity" (p. 6). Fjeld and Barendregt (2009) stated that epistemic action is related to the level of physicality and tangibility in a user interface and provided three spatial planning tools offering different levels of physicality to their participants, then measured epistemic actions by observing the average number of tested blocks in the trial.

Kastens et al. (2008) defined epistemic actions as "actions in the physical environment made with the intent of gathering information or improving cognitive processes" (p. 202). They measured epistemic action by recording the number of non-communicative gestures that participants used to manipulate objects. Kim and Maher (2008) stated that tangibility in user interfaces offers opportunities for participants to relocate objects and test moves to interact with the external representation. Furthermore, they stated that interfaces with physical objects may offer more opportunities for epistemic actions and that these epistemic actions have the potential to reduce the cognitive load of a task carried out in such interfaces. They identified short actions followed by perceptual activities as epistemic actions.

Antle (2013) and Antle and Wang (2013) used the terms direct placement (DP), indirect placement (IP), and exploratory placement (EXP) to describe different actions performed in spatial tasks. DP actions were similar to goal-oriented pragmatic actions, where users already knew where to place an object before picking it up. IP actions, on the other hand, occurred when the user was not initially certain of exact placement and used movements and rotations to identify correct placements. EXP actions were identified as actions by which pieces did not end in the correct destination. IP and EXP actions were similar in characteristic to trial-and-error type actions or epistemic actions. The same action categorization was adopted by Esteves et al. (2015), who elaborated on Antle and Wang's action categorization by expanding it according to different types of epistemic actions.

Antle (2013) suggested that moving and rotating objects using a natural method reduces cognitive load, which allows the opportunity to use cognitive resources for a different task. Antle further stated that object rotation and translation are better supported by interfaces that allow tangible interactions, such as AR interfaces. Therefore, interfaces that afford tangible interaction will reduce cognitive load. Goldin-Meadow (2005) stated that gestures such as epistemic actions provide a communicative purpose as well as providing assistance to the thinking processes; people use gestures when conducting difficult tasks in order to reduce cognitive load. For example, a child who is learning addition will use fingers to add two digits without trying to compute the addition mentally. This reduces the cognitive load imposed and helps the child visualize the problem. Studies have also shown that some cognitive functions, such as the efficiency of spatial memory, may be reduced when gestures are inhibited (Morsella & Krauss 2004). In the current study the way epistemic actions affect cognitive load is analyzed and similar coding method employed by Antle (2013) and Antle and Wang (2013) is used.

Cognitive Load

The cognitive load theory, an instructional theory, states that human working memory is limited in the amount of information it can hold, as well as the number of tasks it can perform using that information (Gerven, Paas, Merriënboer, Hendriks, & Schmidt, 2003). Sweller (1994) acknowledged that new intellectual tasks can vary, and that learning can be extremely simple or difficult depending on different factors.

Moreover, cognitive load can be defined as the total amount of mental activity forced on working memory at an instance in time (Cooper, 1998).

According to Kirschner (2001), the need for competency-based education is continuing to grow. Competencies can be defined as the abilities to work in a fluid environment, deal with “non-routine and abstract work processes,” make decisions and hold responsibilities, work successfully as a team, comprehend dynamic systems, and work “within expanding geographical and time horizons” (p. 2). Kirschner explained that competencies involved in design education are cognitively demanding for learners by asking newly acquired skills to new situations. Students can demonstrate what they have learned through performance changes, and learning requires working-memory capacity.

In order to achieve this type of education style, the limitations of the mind must be understood, and that is where the cognitive load theory comes into play. The cognitive load theory has led to the establishment of many instructional styles, including goal-free problems, worked examples and completion problems (Kirschner, 2001). An important objective of those who develop the curriculum and programs for design education is to design innovative instructional methods and materials that will enhance the ability of learners to comprehend lessons in a straightforward manner and increase the likelihood that what they have learned will be successfully implemented in their work (Abdul-Rahman & du Boulay, 2014).

Abdul-Rahman and du Boulay (2014) examined the effect of different learning styles of students on cognitive load. They recruited 117 college students who were given a pretest to evaluate each of their levels of programming knowledge. These participants were then split into three groups based on the result of their pretests. Each group included an equal, or close to equal as possible, proportion of students who used active or reflective learning styles. Each group learned programming through different teaching styles (paired-method, structure-emphasizing, or completion). After the programming lesson, all participants took a posttest to assess the knowledge gained through each method. Abdul-Rahman and du Boulay found no significant differences in learning outcomes after the posttest was assessed but noted that the different learning styles may have affected cognitive load.

Embodied Cognition and Cognitive Load Theory

Cognitive load theory was first defined by Sweller (1988); he described it with regard to instructional design. Sweller suggested that the design of the instruction should not overload the learner's mental capacity. The working memory of an individual has limited capacity, and overwhelming the working memory reduces the effectiveness of the instruction. For example, if an interface is complicated and difficult to navigate, a higher workload will be imposed on the learner, thereby reducing the effectiveness of the learning process. Similarly, if an interface used in the design process imposes a higher workload on a designer, the effectiveness of the design process is reduced.

In cognitive load theory, three types of cognitive loads are described. *Intrinsic cognitive load* is defined as the level of difficulty associated with a specific task. *Extraneous cognitive load* is described as unnecessary information presented during instruction, and *germane cognitive load* is described as being related to the processes that contribute to creating schemas and rule automation. Cognitive load theory suggests that resources can be allocated to extraneous and germane loads only after allocating resources for intrinsic cognitive load. Some researchers, such as de Jong (2010), have used the term germane cognitive load to explain a type of cognitive load that is not objectively measurable and that has no theoretical basis. In any case, the total accumulated amount of these three types of cognitive loads cannot exceed the capacity of working memory.

Cognitive load is often discussed in tandem with split-attention effect. Split attention effect is described as the effort that a learner has to make to understand pictorial and textual information. Slijepcevic (2013) stated that the split attention effect may be reduced by interfaces such as AR because AR operates by "integrating multiple bits of visual information into one view" (p. 2), thereby reducing cognitive load. Moreover, many studies have suggested that cognitive load can be reduced by AR interfaces (Haniff & Baber, 2003; Klatzky, Wu, Shelton, & Stetton, 2008; Tang, Owen, Biocca, & Mou, 2003).

Kirsh and Maglio (1994) stated that epistemic actions reduce cognitive load because they are physical actions that improve cognition by reducing the memory involved in computation, decreasing the number of steps involved in mental computation, and reducing the probability of error of mental computation. Wilson (2002) stated that cognitive processes are deeply rooted in the body's interactions with the world and that people off-load cognitive work onto the environment. Wilson explained that when people off-load the cognitive task two strategies are used: preloading representation from prior learning and reducing cognitive load by using epistemic actions to change the working environment. By using interfaces that offer tangibility, the resulting epistemic action can be hypothesized to reduce cognitive load.

Measuring Cognitive Load

Brunken, Plass, and Leutner (2003) stated that the methods for measuring cognitive load can be divided into two main categories: measures of objectivity (objective and subjective) and measures of causal relationships. Self-reports and objective observations fall into the first category, while identifying and measuring cognitive load through links with other variables fall in the latter category. Brunken, Plass, and Leutner explained causal relationships with an example of navigation errors, which result from cognitive load caused by an incomplete mental model of the high cognitive load-laden learning environment. They elaborated on other methods such as indirect-subjective measures, direct-subjective measures, indirect-objective measures, and direct-objective measures.

The measurement of cognitive load could also be associated with the three types of cognitive load (intrinsic, extraneous, and germane). Intrinsic cognitive load relates to the difficulty of the subject matter (Cooper, 1998). Therefore, intrinsic cognitive load can be considered to depend on the difficulty level of the subject matter rather than being a property of other elements. Extraneous cognitive load is evoked by the instructional material and does not directly contribute to learning. Germane cognitive load includes processes required to learn the material such as interpreting, exemplifying, classifying, inferring, differentiating, and organizing.

Cognitive load has also been measured by more physical means such as psycho-physiological measures like pupillometry and eye tracking (Klingner, 2010) or neuroimaging (Smith & Jonides, 1997).

While a number of similar methods and tools evaluate and measure cognitive load, one of the more established is the NASA TLX, which assesses subjective mental workload (Galy, Cariou, & Mélan, 2012). Mental workload can be defined as the cognitive demand of a task (Miyake, 2001) and is a measurable dimension of cognitive load (Kablan & Erden, 2008; Kirschner, 2002). The NASA TLX assesses workload on five 7-point scales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. It is available in both a paper and pencil as well as a computer-based version. Its reliability and validity have been evaluated (Hart, 2006; Xiao, Wang, Wang, & Lan, 2005) and it has been established as a valid method for assessing cognitive load.

In a follow-up study 20 years after introducing the NASA TLX, Hart (2006) surveyed 550 research projects that had used the NASA TLX to calculate cognitive load. She found that 6% of the studies were dedicated to measuring cognitive load of virtual or augmented vision. Most of the studies on cognitive load in AR interfaces have focused on its effect on learning (Shirazi & Behzadan, 2015; Slijepcevic, 2013) and task performance (Biocca, Owen, Tang, & Bohil, 2007; Biocca, Tang, Owen, & Xiao, 2006; Medenica, Kun, Paek, & Palinko, 2011; Tang et al. 2003).

Many studies have incorporated NASA TLX. Tracy and Albers (2006) used multiple methods to assess the cognitive load in website design, including NASA TLX as the standard method of measuring cognitive load, the Sternberg Memory Test, and a tapping test. They did not compare these methods but simply suggested that measuring cognitive load provides “an additional level of usability testing besides the normal method of watching a user interact with a site” (p. 259). Windell and Wiebe (2007) compared two methods of measuring cognitive load: NASA TLX and Paas' self-report instrument. They examined whether these two measurements were consistent with each other and if both were equally sensitive across changes in levels of cognitive load and concluded that the two measures provide different outcomes in terms of cognitive load of a PC-based, multimedia-learning environment. Schmutz, Heinz, Métrailler, and Opwis (2009) used the NASA TLX to measure cognitive load of e-commerce applications to understand their effects on user satisfaction, while Jahn, Oehme, Krems, and Gelau (2005) used it to measure the cognitive load in learning programming languages.

Even though the NASA TLX is widely used as a subjective measurement tool to assess cognitive load (Haapalainen, Kim, Forlizzi, & Dey, 2010), Mital and Govindaraju (1999) suggested that self-report measurements are not a reliable indicator of cognitive load. However, the NASA TLX provides a robust and tested subjective measurement of cognitive load by assessing six subscales which include the perceived levels of workload. These subscales measure the perceived workload of physical activity such as perceived physical demand. Especially when the focus is on understanding tangibility and its effect on the work activity, these subscales provide a valid measurement for understanding the cognitive load of interfaces.

Effects of Media Interfaces on Fixation

Media interfaces such as AR employ physical objects, instruments, surfaces, and spaces as physical interfaces to digital information (Ishii & Ullmer, 1997). Such interfaces combine physical representations with digital representations (Ullmer & Ishii, 2000). The current study explores how tangibility in interfaces such as AR can be used in the design process to reduce cognitive load and fixation effects, thereby allowing AR to be used as a tool to enhance the creative design process in design education as well as the design practice.

AR has been defined in many ways. One of the more accepted definitions of AR states that it is a variation of VR (Azuma, 1997). While VR immerses the user in an artificially created digital environment that is disconnected from the surrounding physical environment, AR provides the user with information about the surrounding physical environment by overlaying the virtual over the physical. AR allows 2D and 3D computer-generated objects to be overlain onto physical objects and space, thereby creating a tangible experience for users. The physical interaction affords designers direct, naïve manipulability and intuitive understanding (Kim & Maher, 2005) as well as tactile interaction. This type of interface, in which real objects are enhanced digitally, has been shown to reduce mental work load or cognitive load (Fitzmaurice, 1996; Tang et al., 2003).

Forty years ago, very little was known about the design process, let alone how digital interfaces might affect it. Knowledge about how designers think and work is still being investigated through different viewpoints and methods. Some studies have examined the functioning of the design process, while others have focused on designers' individual traits and the way they design, and still others have examined how design tools are being used in the design process. This study explores how designers use digital interfaces in the design process and how the properties of the digital interface and user perception of using these interfaces impact the design process. Recently there has been much interest in the use of digital design interfaces that generate new skills and viewpoints to create new architectural knowledge. However, there are few or no theoretical frameworks to understand how designers use these interfaces. Understanding how digital design interfaces work and provide support to the design process is essential for the development of digital design interfaces as well as the development of a comprehensive pedagogical agenda for digital design.

Tangible versus Graphical Interaction

For the past two decades, computer interfaces that allow direct interaction have generated much excitement. With the advent of touch screens, little has changed except for mobile device interaction. The WIMP (windows, icons, menus, pointer) interface that people are accustomed to has been efficient in conducting day-to-day activities such as word processing or balancing accounts using a spreadsheet. However, specialized tasks such as graphic design and 3D modeling have required the adoption of alternate interface solutions to use digital technology efficiently in their respective domains. For example, the responsive screen of a Cintique tablet computer can be considered to provide a more efficient means of enhancing a graphic artist's creative process (Howe, 1992).

Different domains require different qualities in a user interface. For example, despite the proliferation of advanced digital design tools, many contemporary designers prefer to use physical models in the design process due to their tangibility. While working with physical models has certain advantages, it also has disadvantages such as the amount of time required to make physical models and the associated costs. Moreover, other fundamental issues such as fixation have been shown to be induced by physical models (Viswanathan & Linsey, 2011). Therefore, identifying what type of interface works best in a particular domain is critical.

In the current study, both a VR interface and an AR interface are examined. The VR interface is a primarily a graphics-based interface controlled through a mouse as an interaction device and driven by the WIMP paradigm. The AR interface is a primarily tactile or tangible interface controlled through physical interaction. Ishii (2007) stated that in AR interfaces the user directly manipulates digital information through hand movements and directly perceives digital information from the physical movement. By contrast, in the VR interface information is manipulated by using controllers such as mice and keyboards.

Direct manipulation (Shneiderman, 1982) is a fundamental concept in human-computer interaction. Some characteristics of direct manipulation include "continuous representation of the object of interest, physical actions or labeled button presses instead of complex syntax, and rapid incremental reversible operations whose impact on the object of interest is immediately visible" (Shneiderman, 1982, p. 251).

A number of studies have been conducted using alternate interfaces and interaction methods for design and design education (Ishii et al., 2004; Ullmer & Ishii, 2000). Systems that use tangibility in interfaces such as URP (urban planning workbench) have been primarily used for the final phase of design. However, researchers have proposed that AR interfaces that use tangible interaction methods can affect design cognition (Bekker, Olson, & Olson, 1995; Tang, 1991), and Kim and Maher (2005) found that AR can be used as tangible design interfaces that affect the designer's cognitive processes.

Embodiment and Tangibility

Embodiment is a concept that is extensively discussed in relation to VR and AR. Dourish (2001) stated that embodiment refers to "the property of our engagement with the world that allows us to make it meaningful" (p. 126) and that people and their actions are embodied elements of the everyday world. Therefore, embodiment is a way of being. In VR and AR environments, a person's feeling that he or she has a body image within the spaces is important, and the level of embodiment becomes crucial in identifying the space that a person occupies in real life. Wilson (2002) related the concept of embodiment to embodied cognition, incorporating the idea that cognitive processes are deeply dependent on the body's interactions with the world. Wilson further stated that cognitive processes are based on our physical interaction in the real world and that the environment is part of the cognitive system. Similarly, Klemmer, Hartmann, and Takayama (2006) stated that this physical interaction with the environment affects one's understanding of the real world. Interfaces with tangibility capitalize on people's natural means of interacting with the environment and provide familiarity, which in turn reduces cognitive load when using those interfaces.

Kirsh (2013) stated that tools change the way people think and perceive, and when tools are manipulated they are absorbed into the body schema, which changes the way people perceive the environment. He further stated that these type of tools become important in interacting with interfaces because people think not only with their minds but with their bodies (which is the premise of embodied interaction). In terms of technology, Dourish (2001) defined embodied interaction as mental and physical interaction with technology. Furthermore, Segal (2011) stated that embodied interaction involves more of the senses than traditional mouse-based interactions.

Research based on embodied cognition theory suggests that tangible interaction by moving and rotating objects supports learning and thinking in problem solving and enhances leaning performance (Bara, Gentaz, Colé, & Sprenger, 2004; Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Jang, Jyung, & Black, 2007; Ramini & Siegler, 2008). Even in traditional childhood education approaches such as the Montessori Method, physical interaction and touch learning are encouraged and the cognitive load of learning is reduced, helping children learn effectively.

Fishkin (2004) discussed the characteristics of interfaces that provide tangibility. In defining these types of interferes he used the broad term TUI. Fishkin used two main characteristics of these interfaces, embodiment and metaphor, in order to create a taxonomy of interfaces that provide tangible interaction. These TUIs are often defined as "giving physical form to digital information" (Ulmer & Ishiii, 2000, p. 580). However, tangible interactions are broadly defined to encompass embodied interaction and embeddedness in physical space to augment the real world (Hornecker & Buur, 2006). Fishkin discusses Embodiment under four categories: full (output device is the same as the input device), nearby (output occurs near the input device), environmental (near the user through other environmental factors), and distant (output occurs at a distance). This categorization of embodiment provided by Fishkin shows the diversity of the concept of embodiment and how it can be used as a scale in categorizing user interfaces. In the current study the output occurs through the same input mechanism.

Direct manipulation was defined by Shneiderman (1982) as the ability to manipulate digital objects on a screen without the use of command-line commands. On a broader scale, Heeter (1991, p. 2) stated that direct manipulation has the following characteristics.

- The objects and actions which can be applied to those objects are visible.
- The interface is transparent.
- The user interacts with objects instead of intermediaries.
- Using the interface feels like driving a car.

Moreover, Wolf and Rhyne (1987) stated that direct manipulation is not a single interface style but a characteristic that is shared by many different types of interfaces.

Millard and Soylu (2009) discussed the differences in direct manipulation in a variety of interfaces, especially WIMP-based interfaces and interfaces that offer tangible interaction. WIMP-based interfaces cause more difficulty due to their complexity, as compared with interfaces that offer tangibility, which provide the user with "direct manipulation in its purest form" (p. 468). Differences in direct manipulation were also documented by Segal (2011), who adapted Shneiderman's (1982) concept of direct manipulation focused on keyboard- and mouse-based interfaces to interfaces that allow natural interactions such as gestures. Segal explored different levels of direct manipulation based on embodiment and how these different levels reduce cognitive load and enhance performance.

The psychological literature confirms that transferring known skills to complete a new task is easier than expending resources to acquire a completely new skill. Therefore, using natural interaction methods provided by interfaces that afford tangible interaction can be hypothesized to consume less cognitive resources than WIMP-based or mouse- or keyboard-based interfaces. While direct manipulation may be the method of interaction in both tangible interaction and WIMP-based interaction, the levels of embodiment in the two types of interface are different. The current study focuses on a WIMP-based VR interface and a tangible AR interface in order to investigate how these interfaces affect the creative design process.

Virtual Reality (VR) and Augmented Reality (AR)

VR has been extensively used in educational environments. As AR technology is becoming more accessible, it is being more often adapted for mainstream use. While VR can generally be interpreted as an immersive three-dimensional computer-generated environment, AR can be thought of as overlaying of the virtual over the physical environment.

VR is a simulated three-dimensional environment which either emulates the real world or acts as an imaginary world. Even though the majority of virtual environments cater to the visual sense, virtual environments can cater to the auditory, haptic, olfactory, and even the taste sense. VR is commonly used as an entertainment, education, and research tool. It offers a wide variety of options and opportunities in conducting research, especially in human behavior research, since virtual environments can be controlled according to the need of the researcher.

AR has been defined as a variation of VR (Azuma, 1997). While VR completely immerses the user inside a computer-generated environment where the user cannot relate to the physical environment, AR allows the overlaying of virtual elements onto the physical environment. AR can be considered a hybrid of virtual and physical environments and therefore supplements reality rather than replacing it. Given the similarities and overlapping of certain characteristics between these two interfaces (AR and VR), there is a critical need to identify advantages or disadvantages of one over the other for its use in a specific domain.

Virtual Reality (VR)

VR can be defined from a technology standpoint (associated hardware) as well as from an experiential standpoint (focusing on experiences such as immersion and presence). On a broader scale, VR is defined as "an alternate world filled with computer generated images that respond to human movements. These simulated environments are usually visited with the aid of an expensive data suit which features stereophonic video goggles and fiber optic data gloves" (Greenbaum, 1992, p. 58) or as "three dimensional realities implemented with stereo viewing goggles and reality gloves" (Krueger, 1991, p. xiii).

Biocca and Levy (2013) provided multiple classifications of VR. One classification was based on the technology used: Windows systems (a computer screen providing a window to an interactive 3D virtual world), mirror systems (superimposing video of the user on a projected system, mirroring his or her action and movements), vehicle-based systems (simulation of a vehicle), and cave systems (room enclosures surrounded by large screens). They also provided two categories of immersive VR systems (Head Mounted Display-based) and AR systems (Head Mounted Display -based). Other researchers have also categorized VR as non-immersive and immersive (Kozhevnikov & Gurlitt, 2013; Mizell, Jones, Slater, & Spanlang, 2002; Robertson, Card, & Mackinlay, 1993). Non-immersive VR systems are often described as computer-simulated 3D environments that are viewed through a computer screen and are manipulated through a mouse and keyboard and therefore belong in the WIMP paradigm.

According to Jacobson (1993), there are four types of VR: immersive, desktop, projection, and simulation. One common denominator across these different types is some form of a device that is used to manipulate the digital environment (such as a mouse, controller, or keyboard). Thurman and Mattoon (1994) used a different approach by identifying a “verity dimension” that they used to differentiate among types of VR. Ultimately, VR environments provide an immersive experience in which users are free to explore and interact in a 3-D world.

In comparison to traditional educational tools, VR offers a number of advantages, including time-efficiency and cost-efficiency. (In some cases, cost-efficiency is highly debatable because VR requires high-end equipment and expensive technology. However, in the context of this study, what is meant here is desktop VR using cost-effective open source or free software.) The use of desktop VR has been increasing through the years, especially in the domain of education. A variety of open-source and cost-effective 3D simulation software allows students the opportunity to create 3D VR simulation using a WIMP-based interface. Even though the potential of using VR in education has been elaborated by many researchers, the cost associated with the necessary hardware and software initially prevented its use in classrooms and design studios that did not have the necessary resources. Recently, however, desktop VR has provided a cost-effective solution for creating VR environments and using them for educational purposes. Dobson (1998) offered the theoretical framework for using desktop VR in design education and stated that these types of VR systems provide about 80% of the functionality of full VR systems.

When it is used in education, VR has also been known to facilitate knowledge acquisition (Mikropoulos, 2001). Some studies suggest that VR offers motivation to students to improve information encoding, retention, and later performance (Huang, Rauch, & Liaw, 2010; Stone, 2001). Nevertheless, some researchers have raised concerns about using virtual environments for educational purposes (Psotka, 2013). Psychophysiological studies have shown that the attention spans of individuals increase in computer-simulated environments (Mikropoulos, 2001). Researchers have also discussed the use of desktop VR specifically in design and design education (Dobson, 1998; Schnabel, 2004). Dobson stated that the real-time immersive system allows students to use it as an active design tool for conceptual design purposes. Chan (1997) stated that VR can be used as a design instrument to increase creativity and as a research tool in design and design education because properties of the interface such as interactivity and representation allow designers to visualize and test design solutions within these virtual environments.

Augmented Reality (AR)

AR has been defined as a variation of VR (Azuma, 1997). While VR completely immerses the user inside a computer-generated environment where they cannot relate to the physical environment, AR allows the overlaying of virtual elements onto the physical environment. AR can be considered a hybrid of virtual and physical environments, and supplements reality rather than replacing it. Azuma (1997) stated that the most common characteristics of AR are that it combines real and virtual elements, it is interactive in real time, and it registers real and virtual objects with each other. Milgram and Kishino (1994) operationally defined AR as any instance in which an otherwise real environment is "augmented" by means of virtual computer graphics and therefore as a middle ground between virtual and physical environments. They described two types of "mixed realities:" augmented reality, in which the physical world is enhanced using virtual elements, and augmented virtuality, in which the virtual environment is enhanced using physical (or real) elements (see Figure 3).

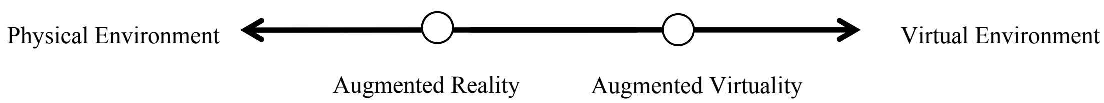


Figure 3. The relationship between the physical environment, augmented reality, augmented virtuality, and virtual environment. Based on Milgram and Kishino's (1994) virtual-physical continuum diagram.

Another type of environment which also can be considered under the AR categorization includes mediated reality systems (MRS), also called computer-mediated reality (CMR). These environments include both diminished reality (certain elements are taken out of the physical setting) and AR (certain elements are superimposed onto the physical setting). Although not exactly a separate category, MRS is seen as another taxonomic system to which AR belongs (Mann & Nnif, 1994). However, in some instances the term MRS is used to exclusively describe diminished reality (Jarusirisawad, Hosokawa, & Saito, 2010).

Normand, Servieres, and Moreau (2012) stated that existing AR taxonomies can be categorized as technique-centered taxonomies, user-centered taxonomies, information-centered taxonomies, and taxonomy based on the target of augmentations. They refer to Milgram and Kishino's (1994) and Milgram and Colquhoun's (1999) taxonomies to explain technique-centered taxonomies based on technology characteristics such as reproduction fidelity and egocentricness/exocentricness. Normand et al. (2012) provided examples of user-centered taxonomies from Lindeman and Noma (2007), Wang and Dunston (2006), and Hugues, Fuchs, Nannipieri (2011) that are based on how users interact with the technology. They also offered examples of information-centered taxonomies from Suomela and Lehikoinen (2004) and Tonnis and Plecher (2011) based on how the technology uses information such as location-based data. Their final category was based on the target of augmentations to classify interfaces in which neither the technology nor the functionalities of the application domain were considered.

Milgram, Takemura, Utsumi, and Kishino (1995) provided a taxonomy of AR similar to the ones that Normand et al. (2012) cited in their study on technique-centered taxonomy. Milgram et al. based their taxonomy on extent of world knowledge (EWK), reproduction fidelity (RF) and extent of presence metaphor (EPM). In this taxonomy they observed the two main types of AR display systems, head-mounted see-through and monitor-based video AR displays. Milgram et al. stated that head-mounted see-through displays "are characterized by the ability to see through the display medium directly to the world surrounding the observer, thereby achieving both the maximum possible extent of presence and the ultimate degree of real space imaging" (p. 284). They further used the terms "non-immersive" and "window-on-the-world" to describe display systems in which computer generated content is overlaid on live video (webcam based) or stored video sources.

Both, non-immersive" and "window-on-the-world" types of AR have been extensively used in different contexts. Many studies have explored the use of AR in education (Billinghurst, 2002; Chen, 2006; Kaufmann, 2003; Pasaréti et al., 2011; Shelton, 2002), particularly why AR would be a good interface for design exploration (Kim & Maher 2008; Seichter & Schnabel, 2005). Even though the use of VR has been documented in design education (De Vries & Achten, 1998), studies focusing on the use of AR in architectural and interior design education are scarce. Very simple AR tasks, such as changing the color of a room in real time, to more complex tasks, such as exploring how a building sits on a site, can be very helpful for designers. Software such as Metaio Creator, which is used to create AR content, and Junaio, an AR browser, allows designers to easily create convincing AR experiences without using any complex coding.

A number of studies have explored desktop AR solutions for a variety of uses including education, medicine, and design and design education (Burke et al., 2010; Chen, 2006; Chandrasekera, 2014; Jeon, Shim, & Kim, 2006). Ibañez, Di Serio, Villaran, and Kloos (2014) investigated the differences in student learning between an AR-based application and a web-based application. Their participants who used the AR-based application had more positive feelings afterward and showed higher levels of concentration while completing their design task, leading to the conclusion that students who used AR attained a deeper understanding of the task than those using a web-based application. While similar studies have been conducted in other educational domains, few attempts have been made to explore the possibilities of using AR in architecture and interior design education.

A desktop AR system uses a webcam, a desktop or laptop computer, and a fiducial marker. The virtual object is overlaid on the marker and displayed on the computer screen. In most cases the webcam is facing the viewer. The cost-effective nature of desktop AR has provided the opportunity for its use in many domains. The number of open source and free or cost-effective software solutions that allow creating these desktop AR experiences have also improved the accessibility of this technology. Previous studies have shown that not only can these type of AR experiences be used in design education but such experiences have been shown to be preferred by design students as an instructional medium as and to improve their spatio-cognitive abilities (Chandrasekera & Yoon, 2015; Martín-Gutiérrez et al., 2010).

Effects of User Characteristics on the Design Process

Digital interfaces affect the design process in a number of ways. It is important to understand how these interfaces affect the design process and thereby the people using them. The purpose of this study is to explore digital interfaces and user preferences for learning.

Research on using digital media in design education has for the most part focused on the development of the technology. Whatever user evaluation has been done has focused on technical aspects rather than using a human-centered approach (Gabbard & Swan, 2008). Nevertheless, both system and user performance measurements are important aspects for AR because the technology coordinates the physical environment and the computer-generated overlaid environment (Grier et al., 2012).

In his 10 books on architecture, Vitruvius (1960) stated that an architect should be a good writer, a skillful draftsman, versed in geometry and optics, expert at figures, acquainted with history, informed on the principles of natural and moral philosophy, somewhat of a musician, not ignorant of the law and of physics, nor of the motions, laws, and relations to each other, of the heavenly bodies (as cited in D’Souza, 2009, p. 173). Apart from these basic technical skills, an architect is assumed to have or acquire imagination and be creative and must gain artistic and intellectual abilities as well (Potur & Barkul, 2007). Isham (1997, p. 2) stated, “The ability to concisely communicate a highly complex and creative design solution has at its creative core visualization skills (internal imaging) that allow designers to mentally create, manipulate and communicate solutions effectively.”

These different characteristics that make a designer may depend on the designer’s innate skills and intelligences as well as the learning method. Thurstone (1938) described intelligence as a combination of factors such as associative memory, number facility, perceptual speed, reasoning, spatial visualization, verbal comprehension, and word fluency. He further identified three factors of spatial ability, mental rotation, spatial visualization, and spatial perception. D’Souza (2006) stated that designers use the seven types of intelligences which Gardener (1983) discusses – logical, kinesthetic, spatial, interpersonal, intrapersonal, verbal, and musical intelligence – and suggested the addition of graphical, suprapersonal, assimilative, and visual intelligences to the types of intelligences so that the framework for design intelligence is more comprehensive.

According to Gardner’s multiple intelligences theory, individuals have a distinctive capacity to succeed in a particular field, and the method of educating these individuals should foster these intelligences. The idea of learning styles suggests that individuals have a particular way of learning that works best for them. For example, some individuals learn more easily from visual activities and some learn more easily from hands-on activities. Educators should identify the learning style best suited for the student.

Understanding the learner preferences of the individual is important when selecting the instructional medium. In this study, emphasis is on learner preference instead of intelligences because this study focuses on the modality through which information is provided to the students (i.e., through the AR or VR interface).

Learning Styles

Researchers have attempted to identify how individuals learn and have provided a number of categorizations. The term “learning styles” was first used in an article by Thelen in 1954, and thereafter has been defined by many. Ausubel, Novak, and Hanesian (1968) defined it as “self-consistent, enduring individual differences in cognitive organization and functioning” (p. 203), while Keefe (1979) defined it as “cognitive, affective, and physiological traits that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment” (p. 2). A general definition of learning styles was provided by James and Gardner (1995) as the different patterns of how individuals learn.

A number of researchers have presented theoretical frameworks that explain these learning styles. Curry’s (1983) onion model explores different learning style theoretical frameworks and provides four main categories: personality learning theories, information processing theories, social learning theories, and multidimensional and instructional theories.

According to the onion model, some learning theories focus on the personality of the individual (such as the Myers-Briggs indicator), information processing theories describe how individuals perceive and process learning activities. Kolb's (1984) model of information processing is an example of this type of theory. Social learning theories describe an individual's interaction with the environment. The fourth type attempts a more holistic view of learning through analyzing multiple dimensions. In his multiple intelligence theory, Gardner described several dimensions of learning, such as inter personal, intra personal, visual-spatial, bodily-kinesthetic, linguistic, and logical (Gardner, 1983).

While many of these theories propose using learning styles as a mechanism to better mold instructional modalities to cater to the individual, the rationale in identifying learning styles in this study is to understand the user preference for digital interfaces and the efficient use of that digital interface in the creative design process. Dunn (1993) stated that

> if individuals have significantly different learning styles, as they appear to have, is it not unprofessional, irresponsible, and immoral to teach all students the same lesson in the same way without identifying their unique strengths and then providing responsive instruction? (p. 30)

Therefore, the logical question that remains is not whether educators should instruct students in different ways but which methods are best for which students.

Learning Styles in Design Education

Learning styles that are applicable to design are defined by the way designers observe and solve design problems. Design educators have explored design students' learner preferences and styles by observing learner preferences of design students (Demirbas & Demirkan, 2003; Kvan & Jia, 2005). Newland, Powell, and Creed (1987) identified four types of design learners by using Kolb's learner styles as a starting ground. Durling, Cross, and Johnson (1996) observed cognitive styles using the Myers-Briggs type indicator (Briggs, 1976) to identify the connection between teaching and learning in design schools.

Students of different disciplines have shown preferences for a certain type of learning style. For example, using the VARK questionnaire, Lujan and DiCarlo (2006) found that medical students prefer multiple learning styles. Felder and Silverman (1988) stated that the learning styles of most engineering students are mismatched with teaching styles of most engineering professors and recommended that professors use different methods to facilitate the learner preference of the students. The learner preference of students from a certain discipline may be similar for a number of reasons, such as shared interests or similar aptitude. In design education, students tend to be more visual and to enjoy working with physical objects such as building prototypes. These preferences and aptitudes may predispose them to a certain learner preference.

Researchers have stated that the most important facet of design and design education is self-reflection, in which a designer would revisit and reflect on the design decisions that have been made (Newland, Powell, & Creed, 1987). Trial and error problem solving encourages and facilitates this type of self-reflective design ideation in enhancing the creative design process (Harnad, 2006). The fact that trial and error type of problem solving plays a major role in a design students' academic career might influence their learner preference as well.

Creativity, Motivation, and Acceptance

Motivation is generally understood as a personal drive to accomplish. Motivation can be intrinsic or extrinsic. Intrinsic motivation is defined as doing something for one's own satisfaction (Amabile & Gryskiewicz, 1987) and extrinsic motivation is defined as "the motivation to work on something primarily because it is a means to an end" (Amabile, 1987, p. 224).

Researchers have studied the connection between intrinsic motivation and creativity (Amabile, 1985; Collins & Amabile, 1999; Hennessey, & Amabile, 1998; Koestner, Ryan, Bernieri, & Holt, 1984) as well as motivation and creativity in the context of design (Casakin & Kreitler, 2010; Kreitler, & Casakin, 2009) and found that when motivation is less, creative output decreases (Collins & Amabile, 1999). Runco (2005, p. 609) stated that "creative potential is not fulfilled unless the individual is motivated to do so, and creative solutions are not found unless the individual is motivated to apply his or her skills."

The technology acceptance model (TAM) uses the perceived usefulness construct to capture associated extrinsic motivation (Davis, 1989). Even though intrinsic motivation was initially included, TAM does not directly capture this construct. Venkatesh (2000) stated that intrinsic motivation affects perceived ease of use. Because technology acceptance is affected by perceived ease of use and perceived ease of use is affected by intrinsic motivation, intrinsic motivation would appear to affect technology acceptance (see Figure 4).

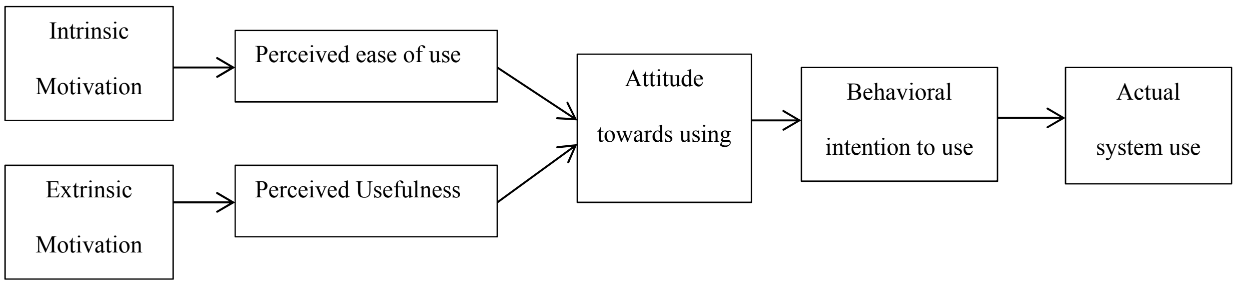


Figure 4. Effect of motivation on the technology acceptance model (TAM).

Perceived ease of use is a predictor of intrinsic motivation and intrinsic motivation enhances creativity. Through this link I examine whether perceived ease of use is related to creativity. Anasol, Ferreyra-Olivares and Alejandra (2013) proposed that the learning experience of kinesthetic learners could be enhanced through the tangibility of user interfaces. They further stated that virtual environments can be used as extensions of traditional physical classrooms, motivating visual or aural learners. Therefore, they suggest that user preference would affect the use of VR and AR interfaces in design and thereby affect the creative design process (see Figure 5).

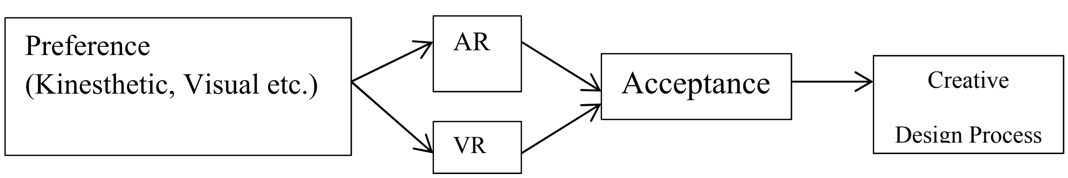


Figure 5. Effect of learner preference through digital modalities. TUI refers to tangible user interface and GUI refers to graphical user interface.

Measuring Learning Styles: VARK Learning Styles Inventory

The VAK (visual, auditory, kinaesthetic) and VARK (visual, aural, reading and writing, kinesthetic) learning style inventories have been used in many studies (Bell, Koch, & Green, 2014; Drago, & Wagner, 2004; Lau, Yuen, & Chan, 2015; Marcy, 2001; Wehrwein, Lujan, & DiCarlo, 2007).

Fleming (2006; Fleming & Mills, 1992) attempted to establish perceptual modes as a measurable construct through the VARK inventory, which focuses on the individual preferences of using different perceptive modalities in obtaining and retaining information efficiently. Aural learners prefer receiving information through discussions, seminars, lectures, and conversations. Visual learners obtain information efficiently through pictures and other visual means such as charts, graphs, and other symbolic devices instead of words. Learners who prefer obtaining information through text are identified as readers/writers. These learners prefer textbooks, taking notes, readings, and printed handouts. Kinesthetic learners prefer to learn through practical examples which also may involve other perceptual modes. They prefer practical examples, hands-on approaches in problem solving, and trial and error solutions to problems. Those who prefer obtaining information through multiple sources are identified as multi-modal.

The VARK Learning styles inventory has gained immense popularity because of its face validity and simplicity, which Leite, Svinicki, and Shi (2010) confirmed using factor analysis to compare four multitrait-multimethod models to evaluate the dimensions in the VARK. They stated that the estimated reliability coefficients were adequate.

Understanding the Design Process via Protocol Analysis

Think-aloud-protocol (TAP) is a research method that has been widely used to analyze the design process and in usability testing as well as human computer interaction research (McDonald, Edwards, & Zhao, 2012). More importantly, protocol analysis has been adopted as a tool in identifying creativity in the design process (Nguyen & Shanks, 2007). In TAPs, participants are asked to verbalize their thoughts either during (concurrent protocol) or after the design process (retrospective protocol).

The validity and reliability of protocol analysis has been a subject of study among many scholars. Those who favor the retrospective protocol claim that participants may not be able to perform two cognitive tasks (thinking and talking aloud) at the same time without distorting the data. Those who prefer the concurrent protocol argue that as participants recall their design process during a retrospective session, they tend to forget and fabricate data. In a study to resolve this matter, Russo, Johnson, and Stephens (1989) compared the reactivity and veridicality of concurrent protocol and retrospective protocols. Reactivity measures whether verbalization changes the primary process and veridicality measures whether the protocol accurately reflects the design process. Russo et al. found that the concurrent protocol satisfied reactivity whereas retrospective protocol was nonveridical. Kuusela and Pallab (2000) further studied the advantages and disadvantages of the two protocols and found that concurrent data provided more information about decision making, while the retrospective method provided more insight about the final choice. McNeill, Gero, and Warren (1998) suggested that two factors should be considered when analyzing protocol data: the adequacy in reflecting the complexity of the data without distortion and the objectivity of the coding protocol. They also indicated that the first issue can be addressed by incorporating coding categories from previous studies and the second can be solved by adjusting for inter-coder reliability.

While TAP studies are used to better understand the underlying cognitive functions and to capture design decisions, the connection between these design decisions are captured by a technique introduced by Goldschmidt (1990) known as linkography. Focusing mainly on linkography, Pouhramadi and Gero (2011) identified the following phases in conducting a complete protocol analysis:

1. Definition of a coding scheme,
2. Recording the activity of designers,
3. Transcription of the recordings,
4. Segmentation of the design discourse according to the coding scheme,
5. Analysis of coded protocols,
6. Definition of links between design steps, and
7. Analysis of the graph of links among design moves (linkography).

Kan and Gero (2008) stated that linkography has two main advantages in studying design protocols. Because the method does not rely on the number of designers and because the length of the linkograph can vary with any set duration, linkographs are said to be scalable in two dimensions. Furthermore, since the design moves and how these moves are linked can be coded separately, linkographs are said to be flexible.

Linkography

Goldschmidt (1990) initially developed the linkography technique to be used in protocol analysis that focuses on designers' cognitive activities. Later, Goldschmidt

(1995) identified units, which she terms “design moves,” that refer to a “step, an act, or an operation that transforms the design situation from the state in which it was prior to that move; design moves are the decomposed, basic components of the protocol” (Goldschmidt, 1995, p. 192). By identifying links among these moves, a linkograph is developed (see Figure 6). Links are established among the moves by asking whether move N is related to other moves from 1 to N-1 (Kan & Gero, 2008, p. 235). Goldschmidt (1995) identified two types of links: forelinks (links connecting subsequent moves) and backlinks (moves that record the path that led to a particular move). Kan and Gero (2008) describe different configurations in linkographs according to how moves are related to each other and provide how entropy of the design process is affected through the links (Table 1).

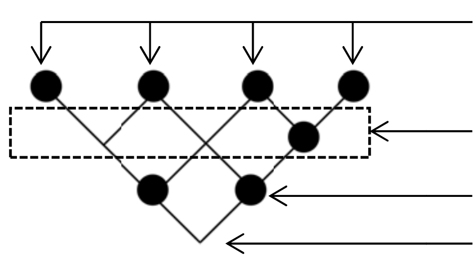
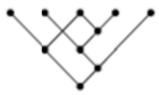


Figure 6. An example of a linkograph.

Table 1

Hypothetical Linkographs, Interpretations, and Entropies

Case	Linkographs	Interpretation	Entropy
01		Five moves are totally unrelated, indicating no converging ideas hence very low opportunity for idea development	0
02		All moves are interconnected, showing that this is a total integrated process with no diversification, hinting that a premature crystallization or fixation of one idea may	0

		have occurred, therefore also very low opportunity for novel idea	
03		Moves are inter-related but also not totally connected, indicating that the process is progressing but not developing, therefore with some opportunities for idea development	5.46
04		Moves are inter-related but also not totally connected, indicating that there are lots of opportunities for good ideas with development	8.57

Adapted from Kan and Gero (2008, p. 336).

Linkography in design protocols has been used to analyze creativity as well as fixation. Kan and Gero (2009) employed the idea of entropy from information theory and applied it to linkography. Entropy is defined as a measurement of the amount of information in the text of the protocol (Shannon, 1948). Kan and Gero showed that a more creative process has higher linkograph entropy than a less creative process. Gero (2011) used the calculated dynamic entropy of a linkograph to measure the fixation in a design process.

According to Shannon (1948), the amount of information carried by a message or symbol is based on the probability of the outcome. Gero (2011) stated that this entropy can be viewed as a measure of the potential of the design activity. If two moves in a design linkograph are linked, the symbol ON is used and if they are not linked, the symbol OFF is used. Kan and Gero (2005, p. 234) provided the formula to calculate the entropy of a linkograph:

$$\mathbf{H = -p(ON)\log(p(ON)) - p(OFF)\log(p(OFF))}$$

In this study, the emphasis is more on identifying fixation rather than on calculating it. Linkoder is a tool that uses the Function, Behavior, Structure (FBS) coding ontology to generate linkographs (Pourmohamadi & Gero, 2011). Linkoder provides outputs of the linkograph (see Figure 7), general statistics, and probability analysis.

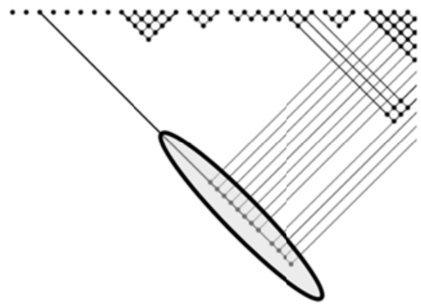


Figure 7. An excerpt of a linkograph showing where fixation is occurring

Creativity, Entropy, and Fixation

In a series of studies conducted by Gero and associates, entropy was used as a method of measuring the creativity of a design process (Gero, 2001; Gero, 2010; Gero, 2011; Gero & Sosa, 2008; Kan et al., 2007; Kan & Gero, 2005; Rosenman & Gero, 1993). Rosenman and Gero stated that innovation and creativity can be identified by observing the quality of the product or the characteristics of the process and said that a creative design system "produces a complex artifact description from information which contains the seeds of the design to only a very small degree at the outset" and originates from "a low level of information content" (p. 438). Goldschmidt (2014) stated that the productivity of design thinking and reasoning can be assessed by observing certain characteristics such as chunks (a block of links among successive moves that form links among themselves) in a linkograph.

In the current study, emphasis is laid on the creative design process, and characteristics of the process are used to identify creativity. The information content that is incorporated in the design process is the indicator of entropy. Kan and Gero (2009) suggested using Shanon's entropy construct as a tool to measure design creativity. They analyzed the design outcome in terms of creativity as well as the entropy of the design process and used linkography to identify creativity in the design process. They concluded that the more creative sessions had higher entropy. Kan et al. (2007) used linkography and Shanon's entropy to measure creativity in 12 linkographs. The results of the study suggested that the overall entropy of design conditions is different in each of the design processes and that the change of entropy might reflect design outcomes.

Gero (2011) suggested that fixation in a design process can be studied by calculating and evaluating the dynamic entropy of a design process. A verbal protocol of a design session can be segmented, and thereafter the segments or moves can be used to create a linkograph that is used to calculate the dynamic entropy. Gero suggested that fixation should result in a sharp drop in information content. Goldschmidt (2014) confirmed Gero's findings on entropy and fixation and reiterated that when fixation occurs in the design process it is signified by a sharp drop in information or dynamic entropy level.

Researchers from different domains have used linkography and entropy calculations in identifying creativity in the design process. Chou, Chou, and Chen (2013) used linkography and its entropy calculations to evaluate creativity in animations. They concluded that the entropy of the linkograph has a high correlation with the evaluation scores on a questionnaire. Chou (2007) suggested a modified method of entropy calculation which uses a pattern-matching algorithm to identify the existence of repetitive pattern inside a layer. Lee (2014) used entropy calculations in the linkograph to measure conditions of creative collaboration in the context of industrial engineering.

In summary, linkography has become an established method to calculate entropy in the design process to identify characteristics such as fixation. The successful and continued use of linkography in many domains makes it a robust tool for understanding the creative design process.

Chapter 3. Method

This study employs a mixed method research design using protocol analysis of qualitative data and quantitative analysis of survey data. The study explores the research questions mainly by closely examining the responses of a small number of participants using a protocol analysis methodology. A between-groups experiment was also conducted to explore any potential difference in the design process between VR and AR environments. The independent variable (i.e., the interaction environment) had two levels: AR environment and VR environment. The design of the study also included learner preference and the dependent variable of technology acceptance (see Figure 8).

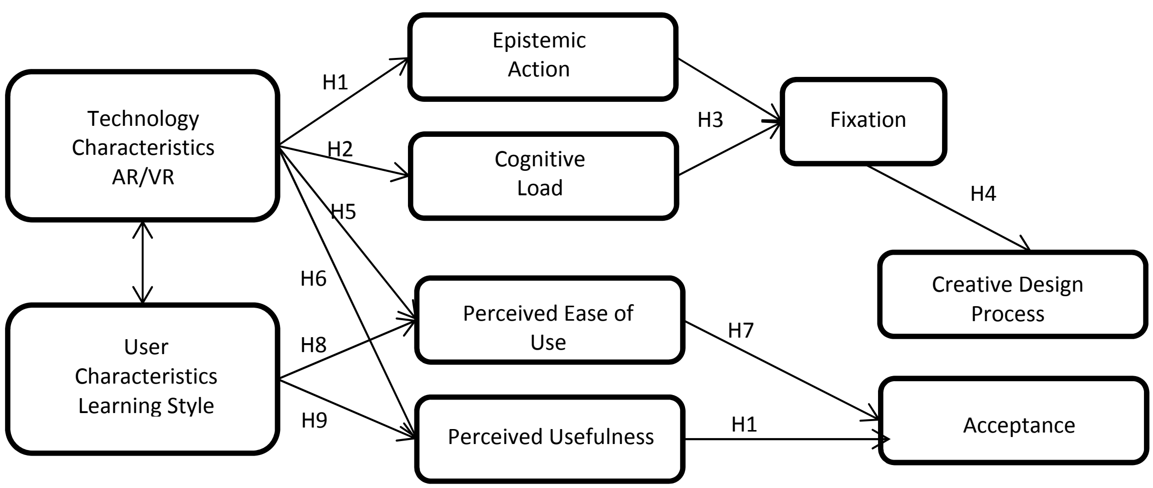


Figure 8. Research variables. AR refers to augmented reality and VR refers to virtual reality.

Research Questions and Hypotheses

This research seeks to answer the following questions:

Research Question 1:

How does type of user interface (AR/VR) affect the creative design process?

RQ1.1: How does interface type affect epistemic actions?

RQ1.2: How does interface type affect cognitive load?

RQ1.3: How does interface type affect fixation?

Research Question 2:

How does type of user interface (AR/VR) and learner preference affect the creative design process?

RQ2.1: How does interface type affect technology acceptance?

RQ2.2: How does learner preference interact with media type to affect technology acceptance?

Hypotheses for RQ1

- H1: The type of user interface used in design problem solving affects a designer's use of design action in ways of epistemic actions.
- H2: The type of user interface used in design problem solving affects the cognitive load required by the user interface.
- H3: The type of user interface used in design problem solving affects fixation in the design problem-solving process.
- H4: The type of user interface used in design problem solving affects creativity in the design process.

Hypotheses for RQ2.1-2.2

- H5: The type of user interface used in design problem solving affects the perceived ease of use (PEU) of the user interface.
- H6: The type of user interface used in design problem solving affects the perceived usefulness (PU) of the user interface.
- H7: The type of user interface used in design problem solving affects the behavioral intention to use (IU).
- H8: The learner preference of the user moderates the PEU of the user interface.
- H9: The learner preference of the user moderates the PU of the user interface.
- H10: The learner preference of the user moderates the IU of the user interface.

The research procedure includes use of the following assessment tools:

- Protocol analysis of the design process: identify fixation, epistemic action, and cognitive load
- Learning style/preference: VARK Learning Styles Inventory (see Appendix A)
- Cognitive Load: NASA TLX (Hart & Staveland, 1988; see Appendix B)
- Technology Acceptance Questionnaire (see Appendix C)

The design is illustrated in Figure 9.

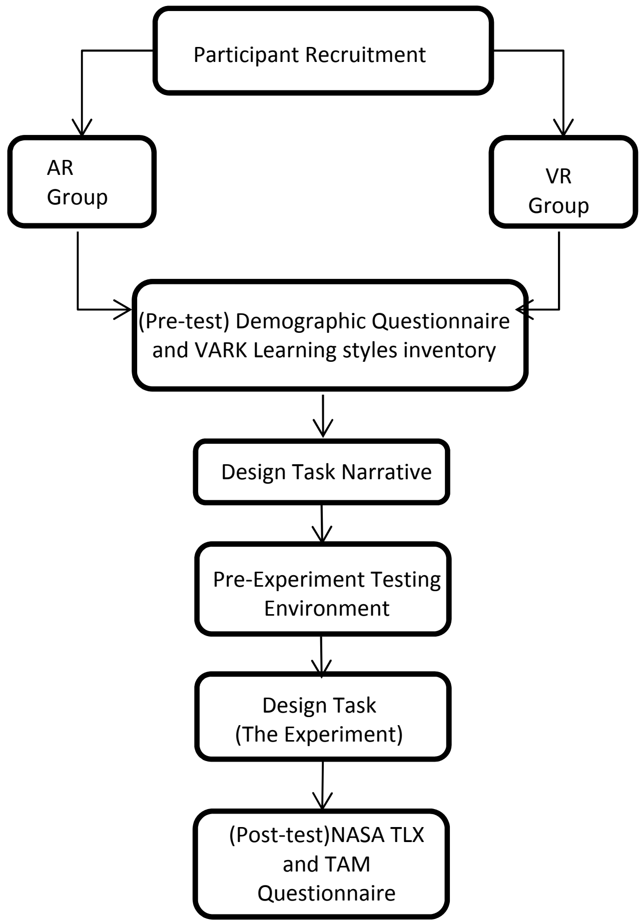


Figure 9. Experimental design.

Participants

Thirty volunteers participated in the study. After approval by the institutional review board (see Appendix C), the participants were chosen by purposeful sampling (Gall, Gall, & Borg, 2007); the recruiting letter can be found in Appendix D. After announcing the research opportunity to design students (juniors and seniors) at a Midwestern university in the US, students were offered a chance to participate in the study. They were informed that there would be monetary incentive of $25 for participating. Volunteers were provided with copies of the informed consent form (see Appendix E). The participants were then randomly assigned to one of the two interaction environments, AR/VR. Even though all 30 participants completed the entire study, only 10 randomly selected protocols were recorded, coded, and analyzed. Only one participant was male; all other participants were female (The participants were representative of the population and gender differences were not considered). One participant was in the age group of 30-35; all other participants were in the age group of 18-25. In the VR group, 7 participants were juniors and 8 were seniors. In the AR group, 9 were juniors and 6 were seniors (see Table 2).

Table 2

Demographics in the Two Groups

	Gender		Age		Academic	
	M	F	18-25	30-35	Senior	Junior
AR	0	15	15	0	6	9
VR	1	14	14	1	8	7

Experiment: Design Problem Solving Tasks

The design project was intentionally selected to be simple and not strenuous for the participants. The design problem was formulated by considering three main factors. The first was to provide a simple problem which would encourage the participants to focus on object manipulation, spatial and logical iterations, context, and user-behavior issues, while also keeping in mind visual appeal, composition, environmental considerations, and ergonomic factors. The intention was to keep the design problem as a close simulation to a studio design problem but at a decreased level of difficulty. This was done out of caution not to make the design problem akin to a formal logic test such as puzzle solving or missing object identification. Design schools administer these kinds of tests in admissions testing, but they may not reflect the reality of university-based design education. Using a simple design problem also made the design sessions shorter in order to allow comprehensive analysis using protocol analysis. When using protocol analysis, appropriate design problems must be developed in order to make the protocol more manageable (Cross, Dorst, & Christians, 1996; Jiang & Yen, 2009).

The second consideration was to formulate a design project that would allow clear identification of epistemic actions. The selected design problem was to arrange furniture within an office space. The interfaces of AR and VR provided the ability to move and rotate these furniture pieces, and the movement of these pieces of furniture would allow clear coding for epistemic actions.

Thirdly, previous studies that have explored traits such as epistemic actions were used as case studies in developing the design problem. Kim and Maher (2008) used similar design problems in their study to observe epistemic actions in TUIs and GUIs. Similar to the current study, they operationalized TUI using an AR interface and focused on creativity in the design process. Fjeld and Barendregt (2009) used a CAD program, BUILD-IT (which is considered a TUI), and physical model-making exercises to identify epistemic action. They employed a series of spatial planning tasks that required participants to move and manipulate objects. These manipulations allowed clear identification of epistemic actions. When describing graspable user interfaces, Fitzmaurice (1996) described a physical handle attached to virtual objects and provided an application by using virtual furniture objects attached to a physical handle that helped in arranging furniture within a layout. In his thesis, Fitzmaurice discussed epistemic action and how epistemic action plays a crucial role in graspable user interfaces. Kim and Cho (2014) used a design problem in which children moved furniture pieces in order to explore epistemic actions and how they affect problem solving skills in children.

In this study, the task was to arrange furniture within a small (15’ X 10’) office space (Figure 11). The floor plan was rectangular and had openings for windows and doors. The participants were asked to consider object manipulation, spatial and logical iterations, context, and user-behavior issues while also keeping in mind visual appeal, composition, environmental consideration, and ergonomic factors.

Design Narrative

Once the participants were briefed and had completed the demographic information survey (see Appendix F) as well as the VARK questionnaire, they were provided with the design narrative in a PowerPoint slide show (see Figure 10), while the researcher narrated. The narration provided participants with information about the design and the expectations for the design problem.

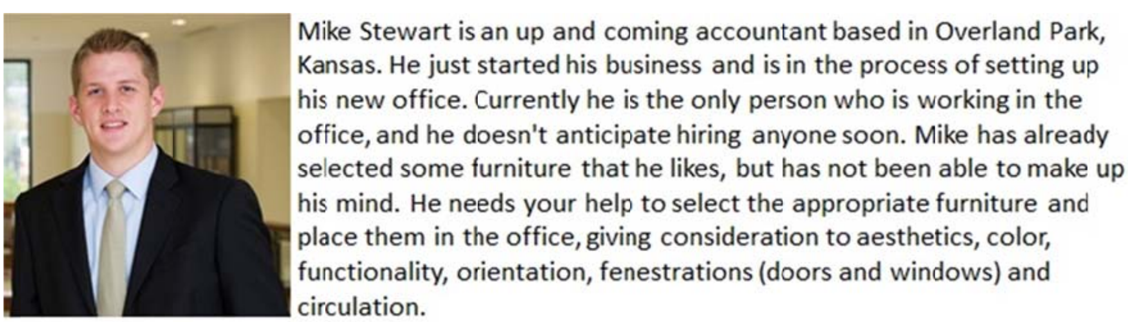


Figure 10. Task narrative presentation slide.

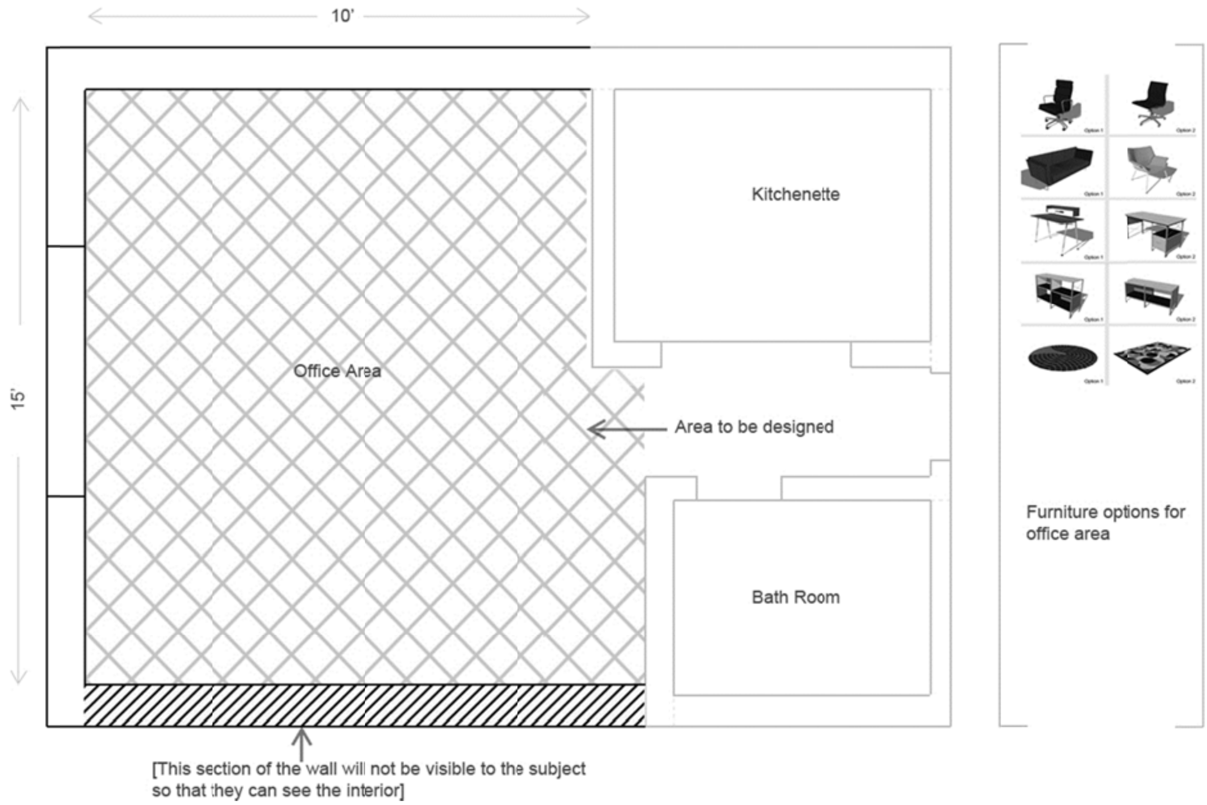


Figure 11. Floor plan of the office space.

However, they were told to take fenestrations, space planning theories, daylight, color, orientation, aesthetics and circulation into consideration. The participants were provided with five types of furniture (see Figure 12) with two choices in each category in order to maintain conformity among the design solutions. All pieces of furniture except the rugs were selected from the Herman Miller office furniture collection. Models of the furniture were downloaded from Google 3D warehouse. The furniture pieces were specifically selected so that the participants would have to make conscious design decisions on the functional and aesthetic appropriateness of aspects such as size, color, space, and material.

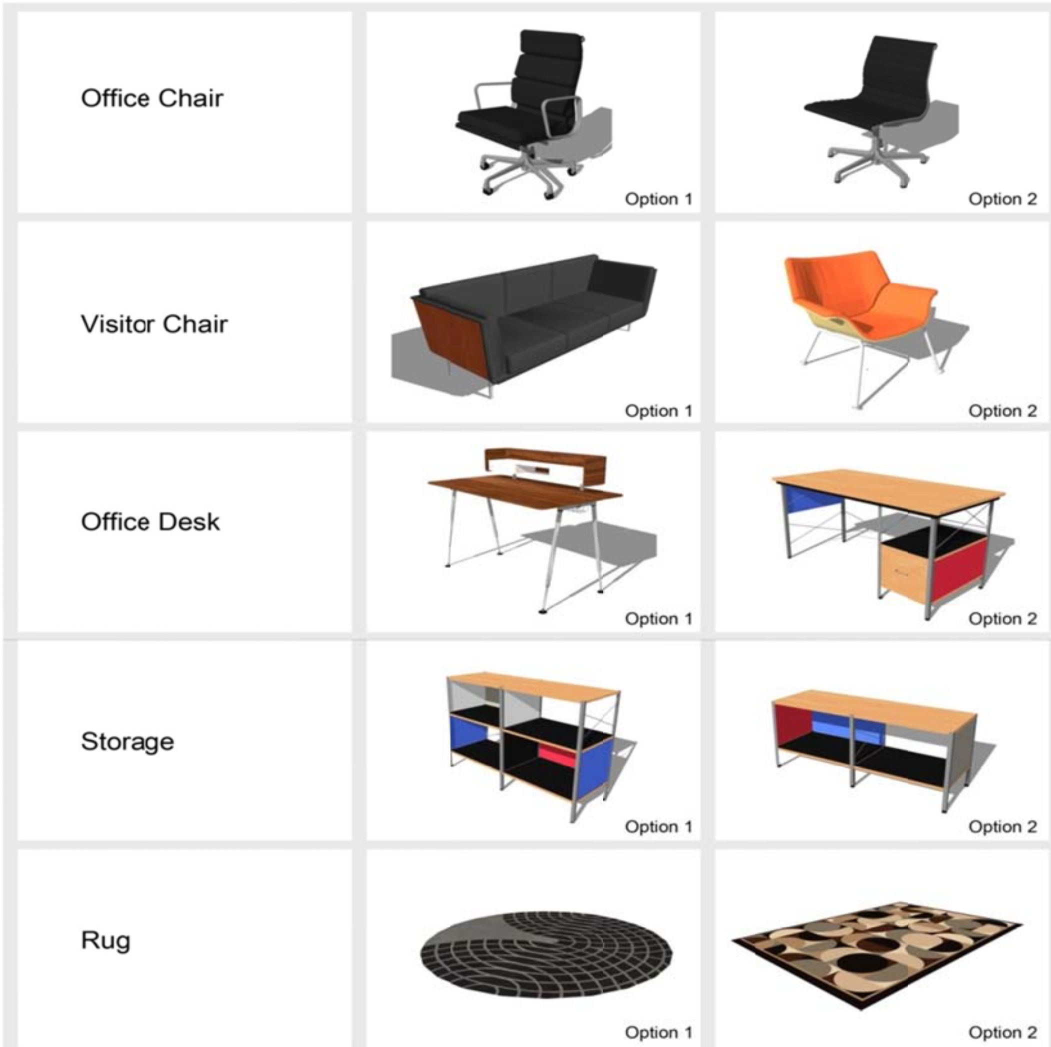


Figure 12. Office furniture.

Experimental Setting

The software BuildAR (New Zealand, Hitlabs) was used in developing the experimental environment. Although the primary use of BuildAR is in creating Desktop AR scenes, it can be used to create both 3D AR and VR desktop scenes. BuildAR uses fiducial markers in order to overlay the virtual objects in physical space. The screen transparency was set to 0 to simulate the VR environment and 100 to simulate the AR environment.

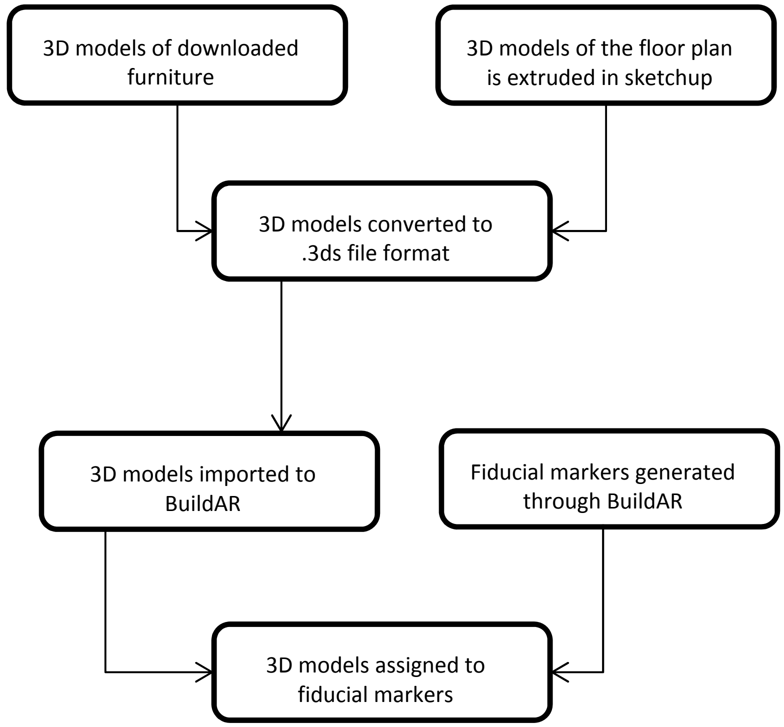


Figure 13. Workflow for augmented and virtual reality model generation.

Object manipulation. In the AR environment, object manipulation was accomplished by moving and rotating the fiducial markers upon which the virtual objects were overlaid. In the VR environment, the participants were able to move, rotate, and scale the objects using a regular PC mouse. However, participants were specifically asked to only move the objects in the X and Y axis/planes and to only rotate around the Z axis. They were also instructed not to scale the objects since all objects were already proportionally scaled.

Training exercise. Participants were provided with a training environment for both VR and AR interfaces, and training was provided for the assigned interface. In the VR environment, they were trained to move and rotate a simple cube using a standard PC mouse as the controller within the BuildAR program (see Figure 14). In the AR environment, they rotated and moved the same cube by moving the fiducial marker upon which the cube was placed (see Figure 15). The testing session lasted approximately 5 minutes, or until the participants confirmed that they were comfortable with the controls. A training manual was provided for both environments and is included in Appendix G.

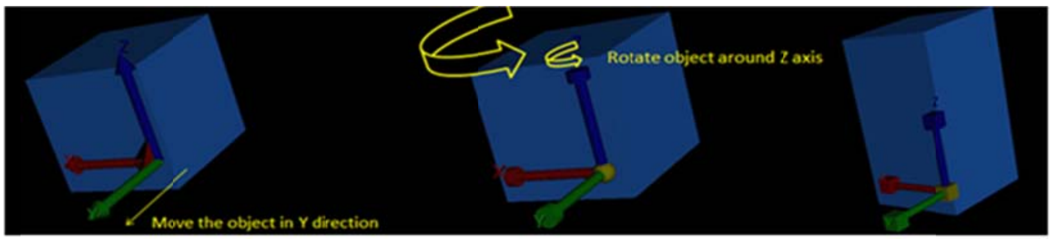


Figure 14. Moving, rotating and scaling in Build AR for the virtual environment.

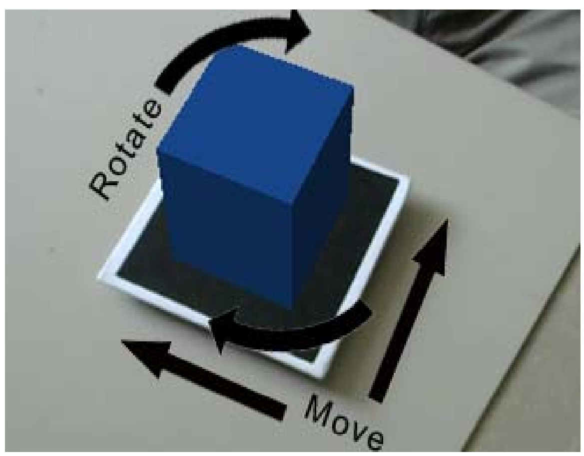


Figure 15. Moving and rotating in Build AR for the augmented reality environment

Augmented reality environment. In this setup, multiple fiducial markers were used for each piece of furniture. 3D models of the furniture were selected and downloaded from the Herman Miller furniture collection on Google 3D Warehouse. The 3D models were opened in SketchUp and exported as .3ds files which can be opened using BuildAR. Each model was assigned a fiducial marker. A total of 11 fiducial markers were used in the AR scene (10 for furniture and one for the plan). The markers were generated through the built-in marker generator of BuildAR. The equipment used for the AR environment included a Dell OptiPlex 9010 desktop PC with 16GB RAM, running the Windows 7 operating system and connected to a standard 22” HD LED monitor, mouse, and external webcam. In the AR interface, the screen transparency was set to 100. Printed fiducial markers were used for tracking the 3D objects (see Figure 16). The marker for the floor plan was located and attached to the base sheet at the top left hand corner so not as to affect other markers, or change position.

a b c

Figure 16. Fiducial markers used in the AR environment: a is the marker; b is the image on the back of the marker; and c is the AR model overlaid on the marker.

The marker block was a 1” X 1” X 0.4” Styrofoam block overlaid with a fiducial marker on the top and an image of the furniture piece on the bottom for easy identification as shown in Figure 17. The participant merely moved and rotated the fiducial markers to locate the furniture pieces in the space demarcated on a blank sheet. Natural light was minimized by using blinds on the windows, and artificial lights were used so that there were no issues with marker recognition. The AR working environment is illustrated in Figure 18. A screenshot of the augmented environment is shown in Figure 19.

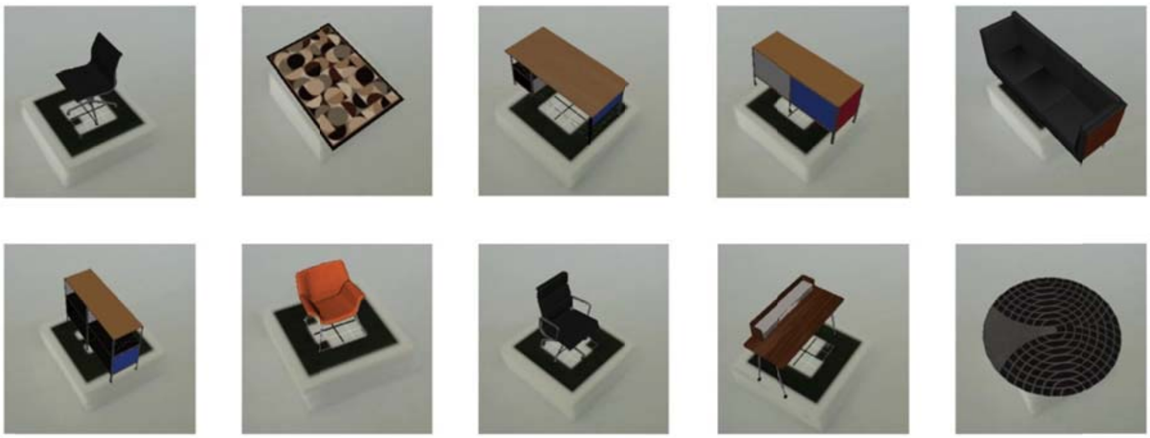


Figure 17. AR furniture models.

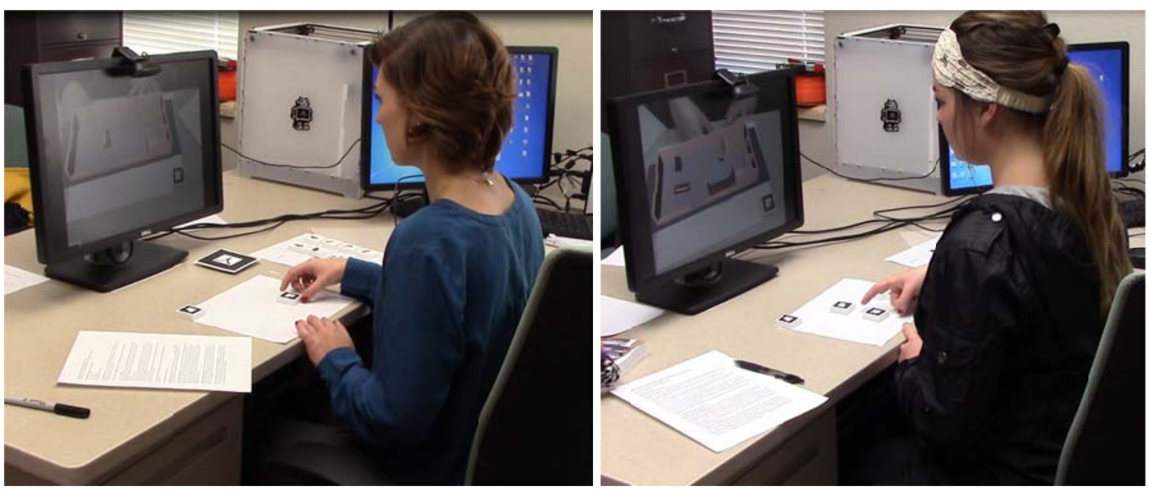


Figure 18. The augmented reality working environment.

Figure 19. Screenshot of the augmented environment.

Virtual reality environment. For the virtual environment the same computer configuration was used. BuildAR was again used with the same marker assignment for the furniture (see Figure 20).

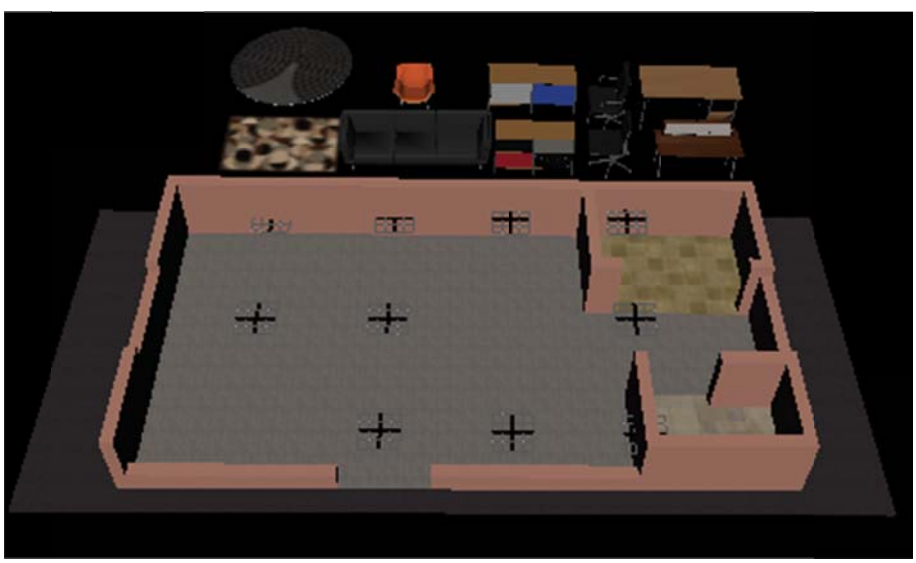


Figure 20. Screenshot of the virtual environment.

There were three main differences in the AR and VR environments. Firstly, in the VR environment a regular PC mouse was used as the interaction device and the manipulation was accomplished by dragging along the axis, while in the AR environment the fiducial markers were used in order to move and rotate the objects. Secondly, in the VR environment the screen transparency was set to 0 and in the AR environment it was set to 100. Thirdly, while in the AR environment each piece of furniture was assigned to a single marker, but in the VR environment all markers were printed on a single sheet (see Figure 21), then moved and rotated using the PC mouse. The VR working environment is pictured in Figure 22.

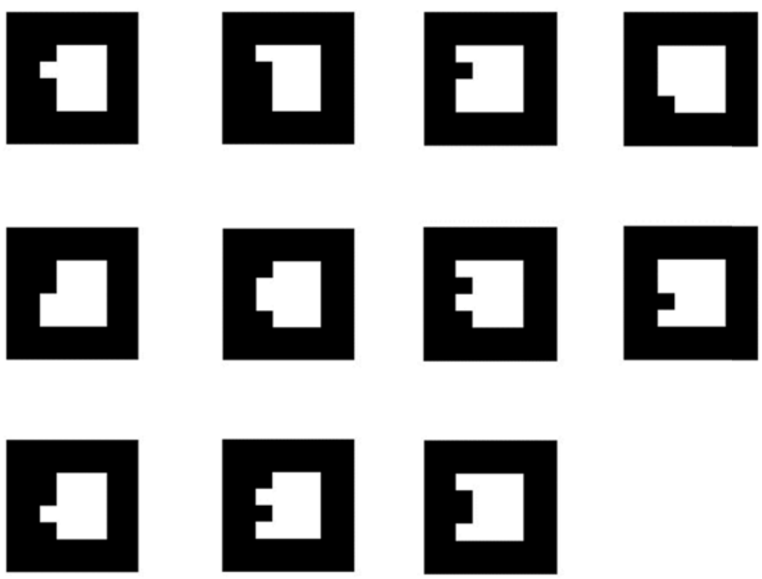


Figure 21. Markers printed on a single sheet.

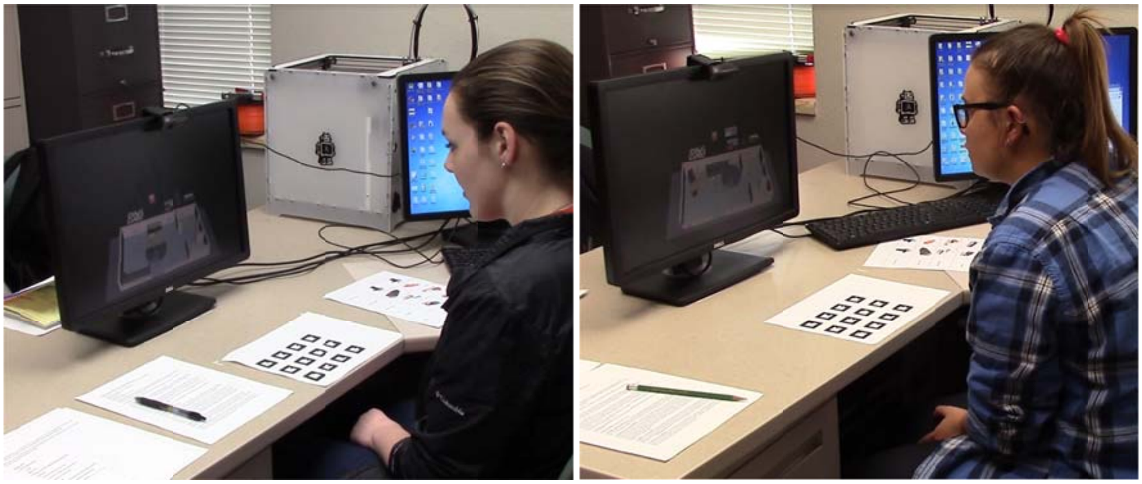


Figure 22. The virtual reality working environment.

Procedure for the Protocol Analysis

All the steps shown in Figure 13 were completed prior to starting the experiment. Visual quality in both VR and AR interfaces was similar. Prior to starting the experiment, participants were instructed on how to use the two types of media and were provided with test environments for both media types.

The participants were introduced to the design project by the investigator and were briefed on the requirements. The participants were instructed to think aloud. Two digital video cameras recorded the participant as he or she was solving the design problem (as shown in Figure 23). The think-aloud protocol was audio recorded. The participant’s completion time was recorded. Ten participants were randomly selected to be used for protocol analysis. Their demographic information is shown in Table 3. The number of participants must be kept small (Chandrasekera, Vo, & D’Souza, 2013; Lindekens, Heylighen, & Neuckermans, 2003) because “in comparison to quantitative studies, with their emphasis on large, representative samples, qualitative research focuses on smaller groups (samples) in order to examine a particular context in great detail" (Borrego, Douglas, & Amelink, 2009, p. 57).

Figure 23. Equipment setup.

Table 3

Demographics of the Participants Who Were Randomly Selected for Protocol Analysis

	Gender		Age		Academic	
	M	F	18-25	30-35	Senior	Junior
AR	0	5	5	0	2	3
VR	0	5	5	0	4	1

Coding of the protocol: Moves and links. In protocol analysis the recorded protocol is divided into smaller units in order to be analyzed. Two main types of such units are commonly used: segments and moves. Suwa and Tversky (1997) defined a segment as one coherent statement about a single item/space/topic. Moves are defined by Goldschmidt (1995) as a step, an act, and an operation which transforms the design situation relative to the state it was in prior to that move. In this study, the units adopted were similar to moves as defined by Goldschmidt (see Table 4).

Table 4

Excerpt of Coding Showing Consecutive Moves in One of the Protocols

Code	Comment
9	I like that rug because it's more colorful...
10	and now I'm going to choose a desk...
	and I'm choosing this desk because it has more storage space
11	I'm going to place it on the rug
12	maybe...can I do that, oh I can't place it on the rug can I?

Linkography has many advantages in design analysis. Because the method does not rely on the number of designers and because the length of the linkograph can be in accordance with any set duration, linkographs are said to be scalable in two dimensions. Furthermore, because the design moves and how these moves are linked can be coded separately, linkographs are said to be flexible. However, one of the main limitations of protocol analysis as well as linkography is its lack of objectivity (Kan & Gero, 2005). In protocol studies researchers use two or more coders to improve objectivity of the coding (McNeill, Gero, & Warren, 1998). Following this example, two independent coders were used in this study. Once the design moves were established, the two independent coders reviewed the moves and assigned links among them.

Kan and Gero (2009) specifically stated that linkography has been criticized for its lack of objectivity in the construction of links. Kan and Gero (2008, p. 319) stated that there are "different levels of subjectivity: determining the moves (segmentation), judging the links among moves (coding), and interpreting the meaning of the resulting linkograph (analysis)." Previous studies have used different methods to assess links between moves. Kan and Gero (2005) stated that links between the moves are established by using common sense. Kan et al. (2007) used a two-step process in identifying links in a protocol. In the first step they used a word search tool to search for occurrence of similar terms, and then in the second process they manually analyzed to see if the words were use in the appropriate context. In another study Kan and Gero (2009) used WordNet, a tool that uses the concept of cognitive synonym (synset) to group words into sets, in order to establish links between moves.

In the interest of enhancing objectivity in the linking process, the current study employed a two-step process. In the first step the transcript of the verbal protocol was analyzed and two coders independently established links among the moves. A word search function was not used in part because the majority of the protocols were short. In addition, the researchers assumed that a word search function would hinder the integrity of the links because of similar words that belonged in different contexts. For example, having two types of chairs (a visitor chair and an office chair) in the transcript might have confused a word search system.

In the second step, the coders went through the video clips of the protocols to confirm that the links were contextually appropriate, as well as to check whether nonverbal cues or movements would suggests additional links. Then the two coders compared the links that they had established independently and after discussion came to an agreement on link placement. Cohen's Kappa was not calculated because there were no disagreements. Even though the two-step linking process consumed more time, the end result was assumed to be more objective and rigorous.

Coding of the protocol: Epistemic action. Epistemic actions were coded using protocol methods adopted from Antle (2013) and Antle and Wang (2013), who used the codes/terms direct placement (DP), indirect placement (IP), and exploratory (EXP) to describe different actions performed. DP actions were similar to goal-oriented pragmatic action where users already knew where to place an object before picking it up, while in IP actions the user was not initially certain of exact placement and used movements and rotations to identify correct placements. EXP actions were identified as those in which pieces did not end in the correct destination. IP and EXP actions were similar in characteristic to trial-and-error type actions or epistemic actions. The same action categorization was adopted by Esteves et al. (2015), who elaborated on the Antle and Wang's action categorization by expanding it according to different types of epistemic actions. However, this falls beyond the scope of the current study in which the intention is limited to identifying epistemic action.

The two independent coders who identified the links between moves coded the recorded protocols to identify epistemic actions. This phase of coding was conducted after the initial protocol was divided into moves and after links were established among moves. Three codes for epistemic action identification were introduced: N-action, which denoted new moves, Rm-action, which denoted Revisit Move moves, and Rr-action, which denoted Revisit Rotate moves. Rm-actions were, distinct moves where the participant changed the position of the furniture, by moving the marker, and Rr-actions were moves where the participant changed the angle of the furniture, by rotating the marker. The Rm and Rr codes were similar in characteristic to Antle and Wang's IP and EXP actions. The N-actions were not considered as epistemic actions as they were the initiating move. In this study the adopted unit of analysis was the number of these moves rather than number of participants. An example of the subsequent occurrence of the two codes Rr and Rm in one of the protocols are presented below.

Move Number		Code
14	turning it to see which way I want it...	Rr
15	and put it in the middle of the room...	Rm

Table 5

Coding for Epistemic Action

Code	**Action**
N	New action
Rm	Revisit move action
Rr	Revisit rotate action

In order to test the validity of the coding scheme, the Cohen's kappa value (Cohen, 1960) was calculated for the protocols using Cohen's kappa formula:

$$K = (Po\text{-}Pc)/(1\text{-}Pc)$$

where Po is the proportion of observed agreement and Pc is the proportion of agreement predicted by chance. Some researchers define poor reliability as a kappa of less than 0.4, fair reliability as 0.4 to 0.6, good reliability as 0.6 to 0.8, and excellent reliability as greater than 0.8 (Trickett & Trafton, 2007). In this study, inter-rater reliability was calculated at 0.67. After negotiations between the coders it increased to 0.89.

Using the analyzed links, linkographs were constructed for the 10 participants using LINKODER software. LINKODER is a tool to analyze coded moves and their linkographs of design protocols (Gero, Kan, & Pourmohamadi, 2011; Pourmohamadi & Gero, 2011).

In summary, the method of analyzing the design process of the participants was protocol analysis using linkography. Think-aloud protocol analysis is a common method used in analyzing the design process, and the linkography technique used in this study allowed the identification of fixation in the design process.

Instruments

Apart from the protocol recording, additional data were obtained from the following questionnaires:

- Demographic information questionnaire (Appendix G)
- VARK Learning styles inventory (Appendix A)
- NASA TLX Cognitive Load Tool (Hart & Staveland, 1988; Appendix B)
- Technology Acceptance Model Questionnaire (Appendix C)

Demographic Information

Basic demographic questions were provided by a paper-based questionnaire. Questions on technology familiarity were also included in this questionnaire, which was completed before the participants completed the design task. The complete instrument is provided in Appendix F.

VARK Learning Styles Inventory

Copyright for Version 7.3 (2001) of the VARK learning styles inventory is held by Neil D. Fleming, Christchurch, New Zealand, and permission for using the tool was obtained from Mr. Fleming. For educational purposes the use of this tool is free; however, under the copyright restrictions only a paper-based version was allowed. The instrument that was used in the study was an unaltered version of the original VARK paper-based questionnaire and consisted of 16 individual items with multiple choice questions. The participants were instructed to mark one or multiple answers as they saw necessary.

The VARK Learning Styles Inventory assesses the learner preference of students through the four sensory modalities of visual, aural, read/write, and kinesthetic. Fleming adapted the existing VAK learning style model into the VARK learning styles inventory. This questionnaire was completed before the participants completed the design task.

NASA TLX Cognitive Load Tool

NASA TLX is a free tool available via download for non-commercial use. There is a paper-based version as well as a digital version. The NASA TLX paper version was used for this study. Because explicit instructions on copyright are not provided through the tool's website, a user agreement was obtained through NASA in order to use the tool. The NASA TLX was administered after the design task was completed.

NASA TLX is a two-part evaluation procedure consisting of both weights and ratings. By combining both a composite score is obtained. In the first part of the evaluation the participants were provided with 15 possible pairs of combination of the six sub scales: mental demands, physical demands, temporal demands, own performance, effort, and frustration. The participants were instructed to circle one of the subscales in each pair that contributed to the workload of the design task. The number of times each subscale was circled was tallied (the scores ranged from 0 to 5). The numbers were considered as the weight of each subscale and were entered in the Sources of Workload Tally Sheet from the NASA Task Load Index tool (Appendix H). This was considered the weight score for the subscale.

In the second part of the evaluation, the participants were provided a sheet with the subscales and rating scales. Participants circled the scale based on the magnitude of the effect of the particular subscale on the design task. This was considered the raw score for the subscale. Using the Weighted Rating Worksheet (from the NASA Taskload Index tool; Appendix H), the raw score was multiplied by the weight score for each subscale to obtain an adjusted rating for each subscale. The sum of the adjusted ratings of each subscale was then divided by 15 to give an absolute workload or the cognitive load of the design task in the respective interface (AR and VR). Some researchers have stated that the weighting procedure can be eliminated and have only used the raw test score to obtain the workload for a specific task in order to simplify the process (Hoonakker et al., 2011). However, even though this is a rigorous process and takes time to administer as well as to calculate, for this study both parts of the procedure were necessary in order to obtain the cognitive load imposed on the design task by the interface.

Technology Acceptance Model Questionnaire

The 16-item TAM questionnaire was based on previous TAM questionnaires (Davis, 1989; Venkatesh, 2000) and was a modified version of previously used TAM questionnaire (Chandrasekera & Yoon, 2015). The paper-based questionnaire was administered after the design task was completed.

Chapter 4. Part 1- Design Process

Objectives and Hypotheses

The objective of this section is to analyze the effect of interface type on epistemic action and cognitive load, which affects fixation in the design process. The study investigates the following research questions and hypotheses using linkography within a protocol analysis.

Type of user interface (AR/VR) and its effect on the creative design process

RQ1.1: How does interface type affect epistemic actions?

RQ1.2: How does interface type affect cognitive load?

RQ1.3: How does interface type affect fixation?

- H1: The type of user interface used in design problem solving affects a designer's use of design action in ways of epistemic actions.
- H2: The type of user interface used in design problem solving affects the cognitive load required by the user interface.
- H3: The type of user interface used in design problem solving affects fixation in design problem solving process.
- H4: The type of user interface used in design problem solving affects creativity in the design process.

Linkography

The following analysis is based on the data collected in the protocol analysis section of the study. The focus was on finding patterns of designers' behaviors and cognitive actions by interpreting information shifts, specifically looking for significant differences between the data collected from the AR sessions and the data collected in the VR sessions. The LINKODER tool was used to create and analyze the linkographs.

Kan, Bilda, and Gero (2006) stated that

> If an idea is weak, it will not have many forelinks and this is represented by a low entropy. However, if an idea has too many forelinks, this might indicate fixation; this is also indicated by a low entropy. Backlink entropy measures the opportunities according to enhancements or responses. If an idea is very novel, it will not have backlinks, the resulting entropy is low. On the other end if an idea is backlinked to all previous ideas, it is not novel hence is represented by a low entropy. Horizonlink entropy measures the occurrence of incubated segments and low horizonlink entropy indicates complete cohesiveness. Horizonlink entropy measures the opportunities relating to cohesiveness and incubation. (10)

They also stated that intensive linking in design moves may yield good designs. Fixation should not occur early in the design process. Kan and Gero (2007) suggested that forelink entropy measures the idea generation opportunities in terms of new creations or initiations.

The following design protocols were coded and analyzed using the design protocol explained in Chapter 3.

Analysis and Discussion

Augmented Reality Participant 1. Linkographs and descriptive statistics from the first participant are shown in Figure 24 and Table 6.

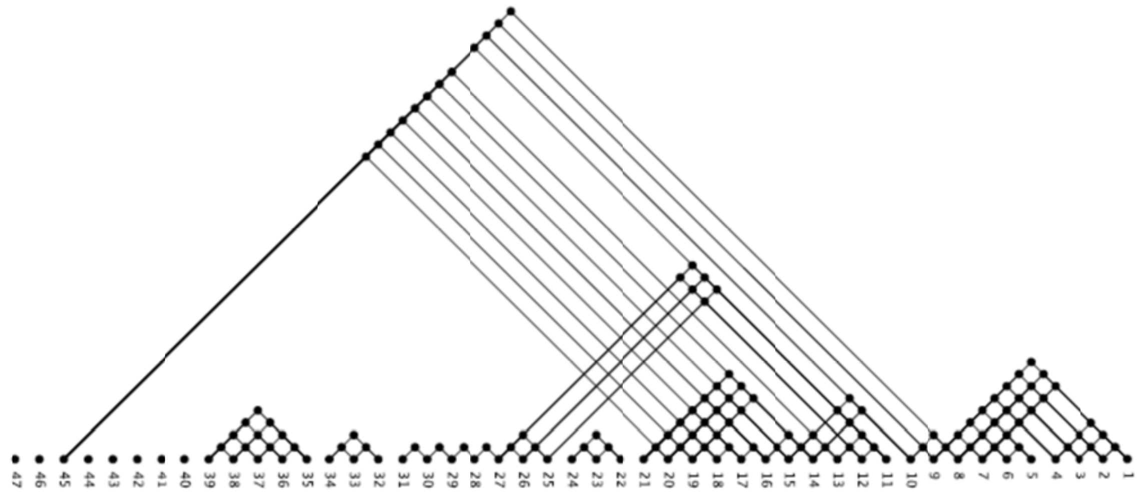


Figure 24. Linkograph for the design protocol of augmented reality participant 1.

Table 6

Descriptive Statistics for Augmented Reality Participant 1

Variable	Statistic
Total Moves	47
Total Links	103
Link Ratio	2.19 per move
Forelink Entropy	16.433
Backlink Entropy	14.183
Horizonlink Entropy	10.340

The overall forelink entropy (Figure 26) is higher than backlink and horizon entropies and does not indicate strong fixation. Overall backlink entropy (Figure 27) is neither very high nor low. The overall low horizonlink entropy (Figure 25) suggests cohesiveness in the linkograph. The entropy graphs indicate that the horizon and forelink entropies are high when the design process started, and the forelink entropy continues to remain above the mean entropy level for the most part of the design process. High entropy is associated with productivity in the design process. Kan and Gero (2005) suggested entropy as a measure to analyze the potential of design sessions. Qualitatively, there are two dramatic drops in the forelink entropy graph shown in Figure 25. The first drop occurs around moves 28 to 34 when the participant was trying different options without any particular reasoning.

29 and add a visual appeal to it

30 Now I'm moving everything back

31 so that it is up against the wall

32 and not directly in the middle of the room

The second drop occurs at the end of the session. The linkograph protocol shows that the participant is reviewing the design decisions without adding new information. This is typical in most design sessions encountered during the study. The latter potion of the design protocol tends to have low entropy and is shown as a drop in the entropy graphs. Sharp increases in entropy are seen in the early design phase when there is a lot of activity generating new ideas. This was observed in most of the protocols analyzed and was expected because in the early design phase entropy is thought to be high because the designer is using new information and ideas. The sharpest increase in entropy occurs around moves 15 to 19. This is when the participant is compiling ideas that center on the placement of the desk and how that connects to the pieces of furniture as well as the layout.

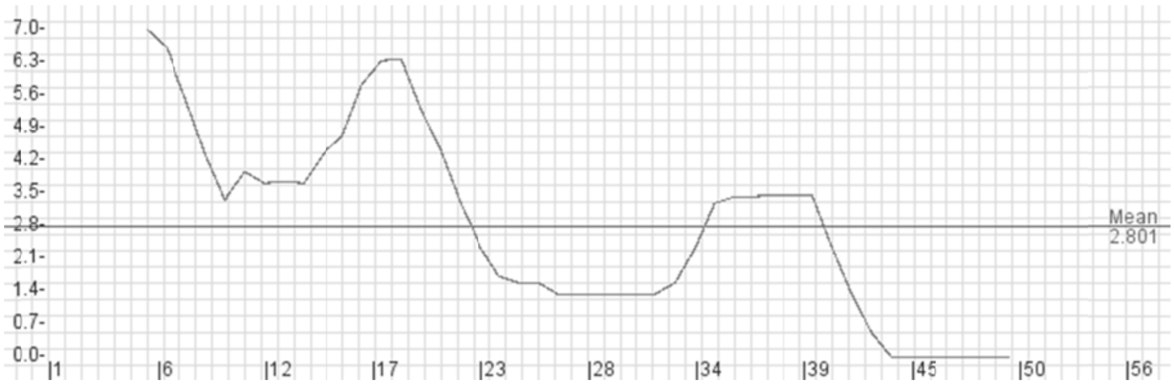


Figure 25. Horizonlinks entropy for augmented reality participant 1.

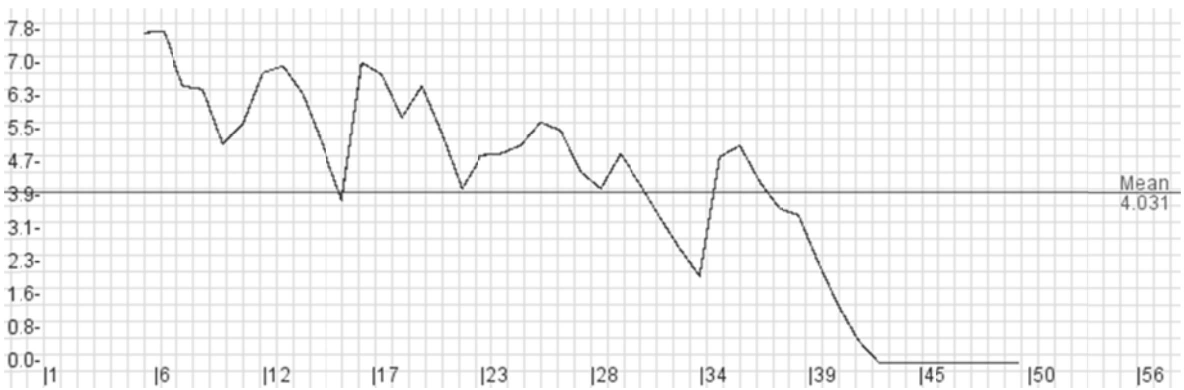


Figure 26. Forelinks entropy for augmented reality participant 1.

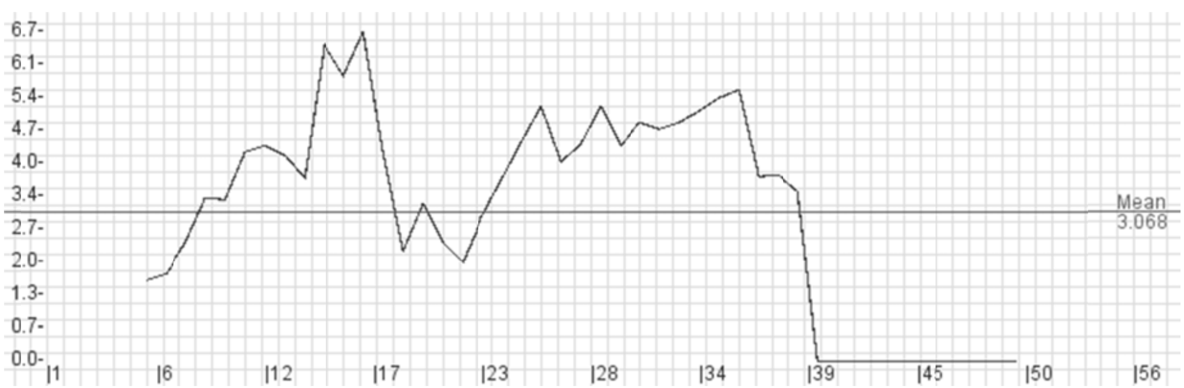


Figure 27. Backlinks entropy for augmented reality participant 1.

Augmented reality participant 2. The linkograph and descriptive statistics for AR participant 2 are shown in Figure 28 and Table 7.

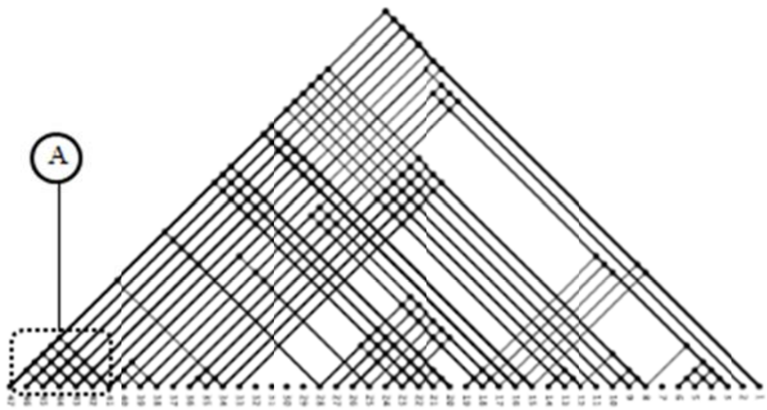


Figure 28. Linkograph for the design protocol of augmented reality participant 2.

Table 7

Descriptive Statistics for Augmented Reality Participant 2

Variable	Statistic
Total Moves	47
Total Links	191
Link Ratio	4.06 per move
Forelink Entropy	17.301
Backlink Entropy	25.085
Horizonlink Entropy	25.756

In this protocol, the overall forelink entropy (Figure 30) appears to be lower than overall backlink (Figure 31) and horizon entropies (Figure 29), which indicates fixation in the design process. Furthermore, the linkograph diagram has areas that can be identified as saturated links (marked as "A"). Saturation is an indicator of fixation. However, the total backlink entropy is lower than horizonlink entropy. Because horizonlink entropy measures the opportunities for cohesiveness and incubation, this suggests that there were opportunities for idea incubation. The forelink entropy continues to be above the mean until move 24. Then there is a rapid reduction of entropy.

23 as people walk in they will have a place to sit

24 as it would face the person they need to see most

25 And I believe that having this

26 Trying to figure out if this one would go better on the side

27 where it is able to be reached or if he wants an open plan

28 I feel like putting it with …

29 putting it right up to the desk will be a little bit better

30 as it will give more of a collaborative appeal to it

The contents of the design moves do not effectively relate to other concepts in the design directly and therefore do not appear to have many forelinks with the other moves. The entropy level increases until the design process nears the end, at which point it decreases. This was seen in other protocols as well. The only difference is that the horizonlink entropy level is higher between moves 17 and 24. These moves suggest that opportunities were present for the incubation of ideas.

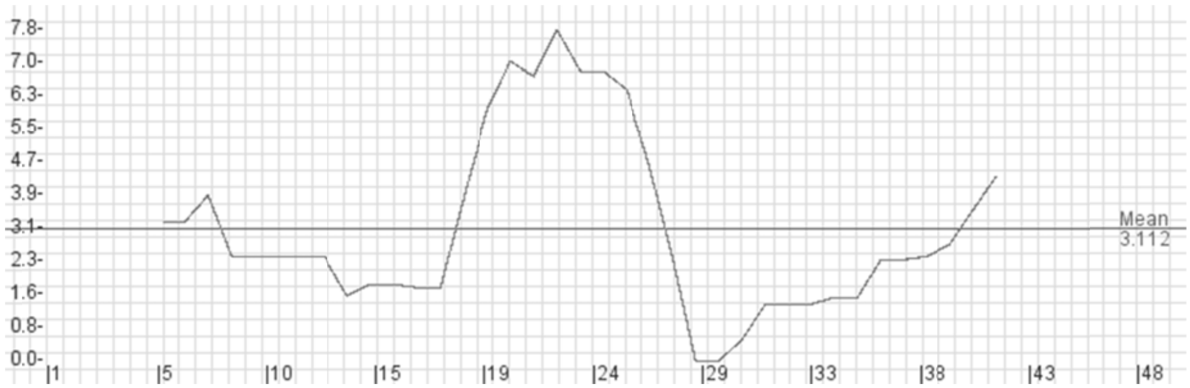


Figure 29. Horizonlinks entropy for augmented reality participant 2.

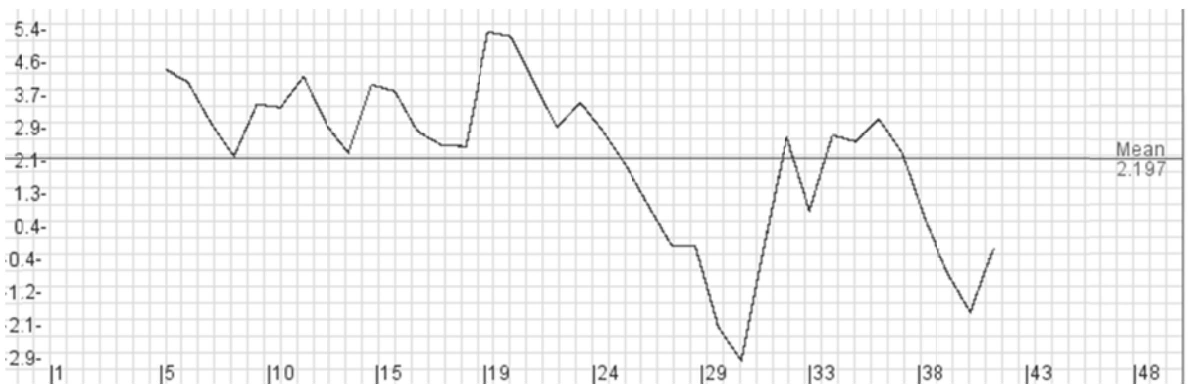


Figure 30. Forelinks entropy for augmented reality participant 2.

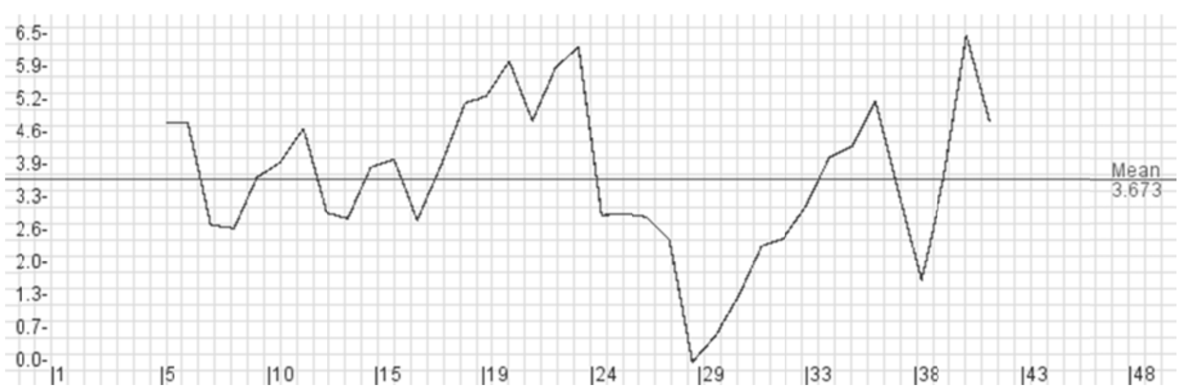


Figure 31. Backlinks entropy for augmented reality participant 2.

Augmented reality participant 3. The linkograph and descriptive statistics for AR participant 3 are shown in Figure 32 and Table 8.

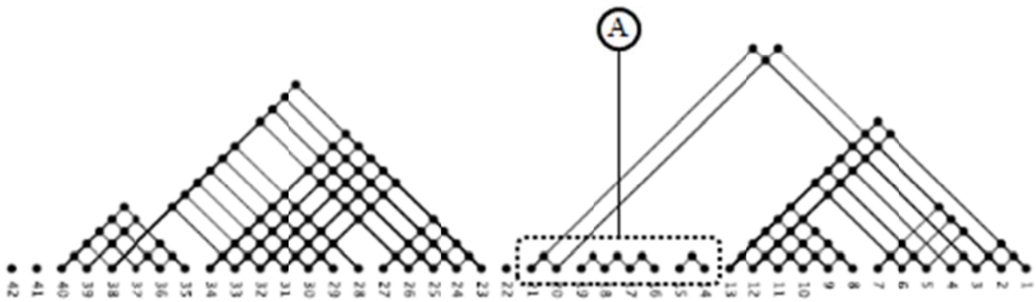


Figure 32: Linkograph for the design protocol of augmented reality participant 3.

Table 8

Descriptive Statistics for Augmented Reality Participant 3

Variable	Statistic
Total Moves	42
Total Links	116
Link Ratio	2.76 per move
Forelink Entropy	20.467
Backlink Entropy	17.233
Horizonlink Entropy	9.935

The overall forelink entropy (Figure 34) is higher than backlink (Figure 35) and horizonlink (Figure 33) entropies and does not indicate strong fixation. Total backlink entropy is neither very high nor low. The overall horizonlink entropy is low and suggests not enough opportunities for the incubation of ideas. The entropy graphs indicate that the horizonlink and forelink entropies are high at the beginning of the design process; however, the forelink entropy suddenly drops as the design is initiated. This drop is because of the rapid changes from one idea to another without any cohesive explanation. More than 50% of the moves remain above or close to the mean forelink entropy, which suggests that the protocol was rich in information and few opportunities for fixation were present. The first major drop occurs around moves 24 to 28 when the participant was asking the researchers questions about the design. However, these questions did not pertain to the design solution.

24 I have a question. Because there is only one side chair is that like his only option?

25 Is that like his only option?

26 He only gets one chair?

27 Hah well then I take that back and pick the sofa

28 for more options of chairs…there we go

Furthermore, from move 14 through 21 a series of sawtooth track patterns is seen (marked as “A”). Sawtooth patterns are defined as a sequence of moves linking each to the preceding move (Goldschmidt, 2014, p. 65). Kan and Gero (2008) stated that this type of pattern is an indication that the process is moving forward but not developing. The second drop occurs at the end of the session and the linkograph protocol shows that like previous instances, the participant is reviewing the design decisions without adding new information.

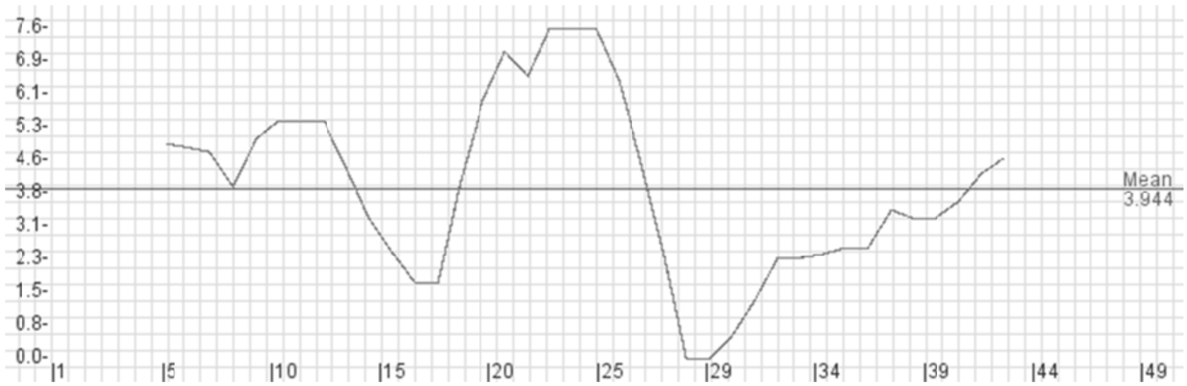


Figure 33. Horizonlinks entropy for augmented reality participant 3.

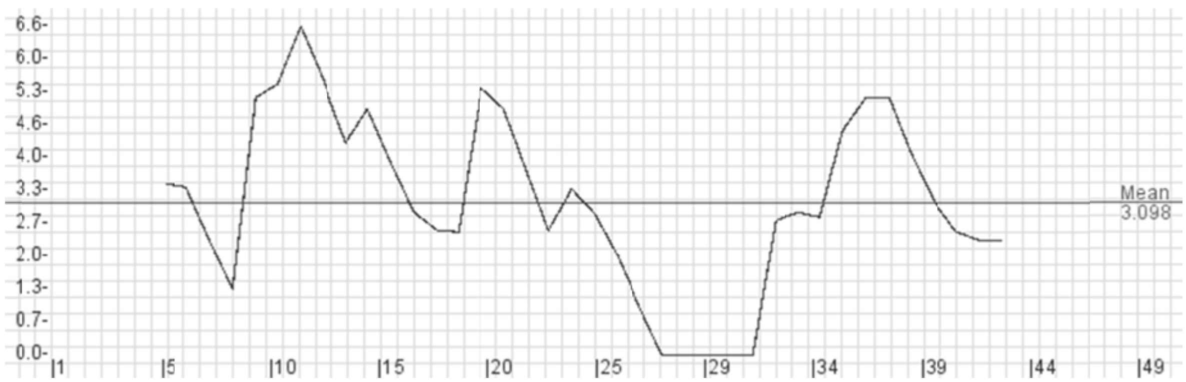


Figure 34. Forelinks entropy for augmented reality participant 3.

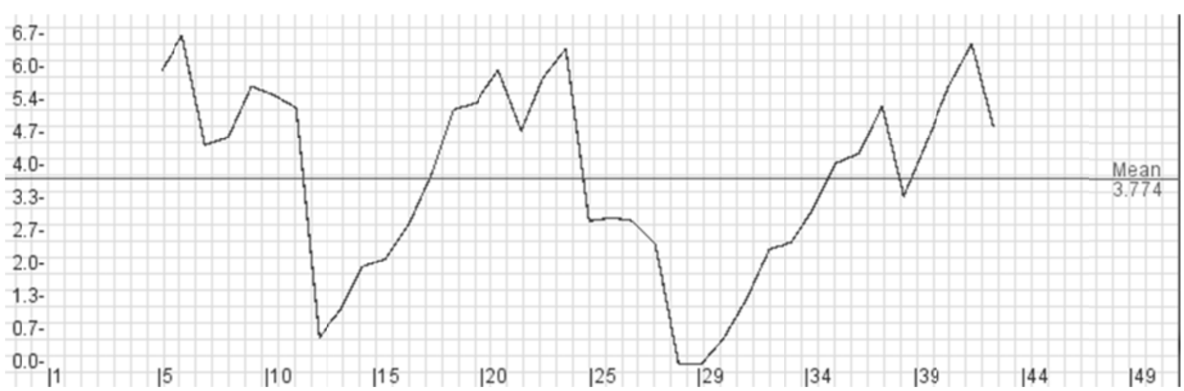


Figure 35. Backlinks entropy for participant 3.

Augmented reality participant 4. The linkograph and descriptive statistics for augmented reality participant 4 are shown in Figure 36 and Table 9.

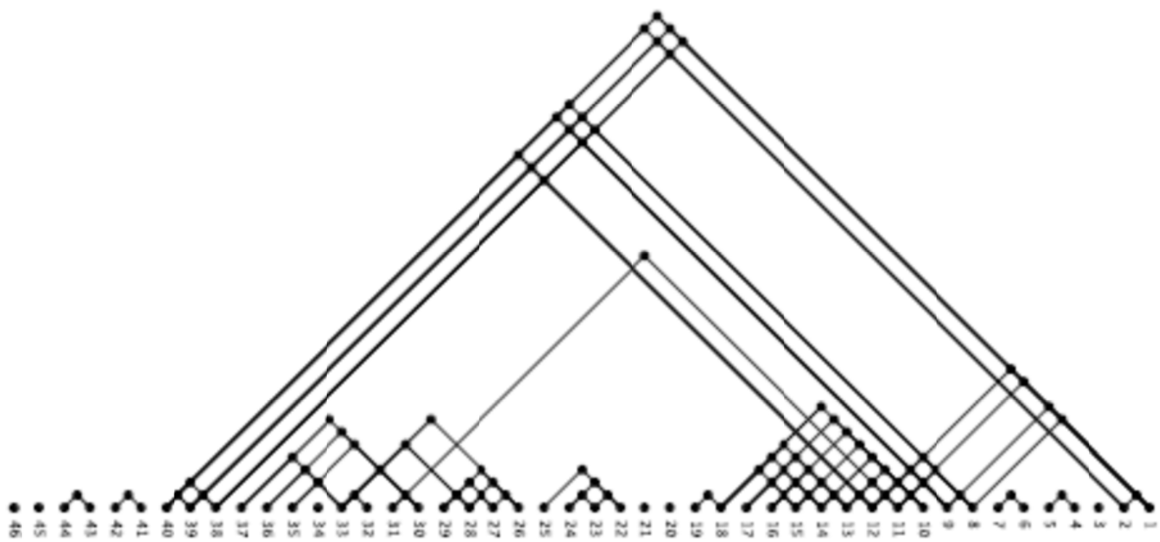


Figure 36. Linkograph for the design protocol of augmented reality participant 4.

Table 9

Descriptive Statistics for Augmented Reality Participant 4

Variable	Statistic
Total Moves	46
Total Links	78
Link Ratio	1.7 per move
Forelink Entropy	13.715
Backlink Entropy	15.854
Horizonlink Entropy	10.581

At first glance, what is unique in this linkograph is that the backlink entropy (Figure 39) is higher than the forelink (Figure 38) and horizonlink entropies (Figure 37), which suggests few opportunities for novel ideas. However, the difference between the backlink and forelink entropies is just two levels. This is also suggestive of fixation occurring during the design process. However, the occurrence of fixation needs to be analyzed within the design protocol to understand how and why it occurred. The linkograph illustrates that only one-third of the entire protocol was in the range of the mean entropy level.

The design process does not start with a high entropy level. This is probably because the participant is trying to figure out how to correctly use the software, even though she had the chance to test it prior to beginning the design problem.

2 ...trying to figure it out......

3 the couch keeps popping up by the way....oh...

4 which way am I going oh it's the opposite...

5 oh yeah...

6 I'm trying to figure out where the blinds are...I meant the walls...of the building...

7 ok...I'm sorry I'm trying....ok.

Despite the low overall forelink entropy, high entropy surges can be observed on the graph. One of the major increases in entropy occurs between moves 12 to 16, when the participant is connecting these moves with other ideas during the design process. Moves 24 to 30 also provide high forelink entropy.

24 and it's away from the door

25 and I chose the couch so that more people can sit there now...

26 I want the desk chair...

27 Put behind the desk...

28 and figure it out where it goes...ok...

29 there we go...

30 now for some storage

31 this one has more shelving....

After that the forelink entropy remains below the mean entropy level for the most part.

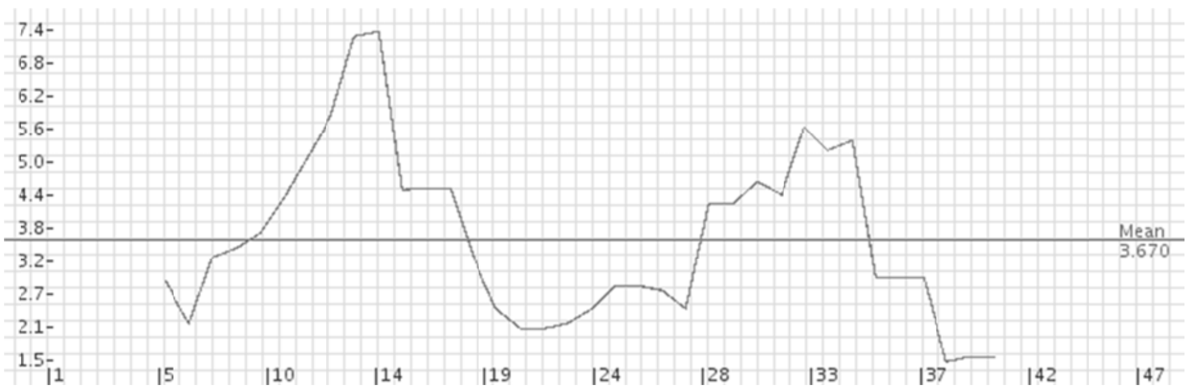


Figure 37. Horizonlinks entropy for augmented reality participant 4.

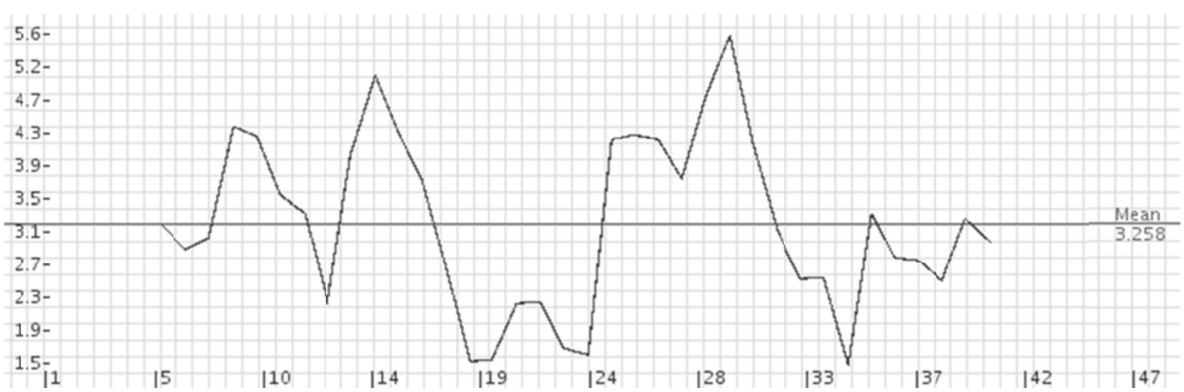


Figure 38. Forelinks entropy for augmented reality participant 4.

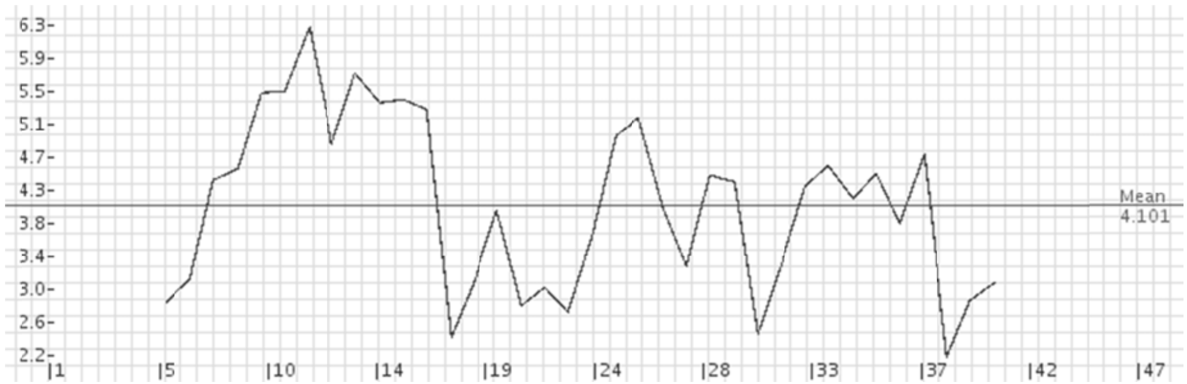


Figure 39. Backlinks entropy for augmented reality participant 4.

Augmented reality participant 5. The linkograph and descriptive statistics for AR participant 5 are shown in Figure 40 and Table 10.

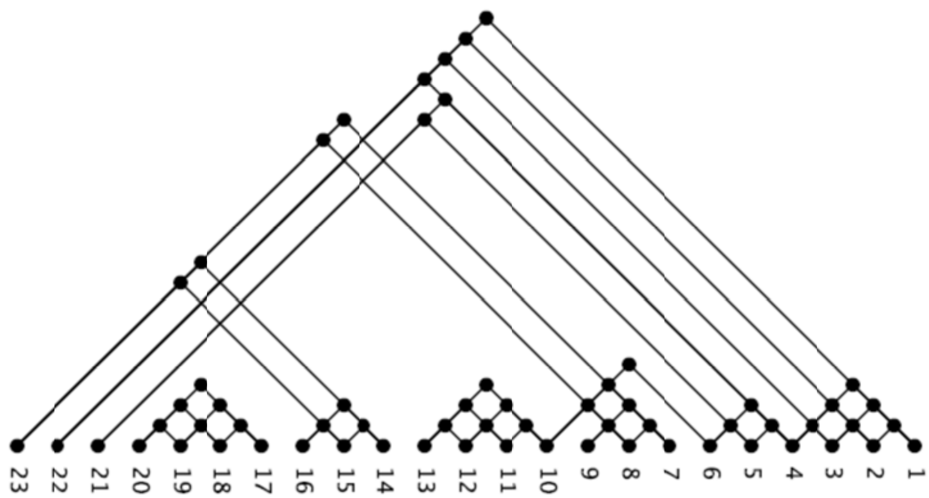


Figure 40. Linkograph for the design protocol of augmented reality participant 05.

Table 10

Descriptive Statistics for Augmented Reality Participant 5

Variable	Statistic
Total Moves	23
Total Links	40
Link Ratio	1.74 per move
Forelink entropy	11.227
Backlink entropy	10.316
Horizonlink entropy	9.153

The entire design process for participant 5 was fairly short; she had the least number of moves of all other participants. (This protocol, like the others, was randomly selected for linkographing.) While the entropy levels are on the low side, the forelink entropy (Figure 42) is high. This pattern suggests that even though fixation occurred there are no prominent fixation episodes. The horizonlink entropy (Figure 41) is lower than the forelink and backlink entropy (Figure 43) levels, which suggests few opportunities for incubation of ideas. Except for two brief periods, one at initial stages and one at the later stages, the forelink entropy tends to revolve around the mean.

A drop in entropy occurs during moves 13 through 16. Examination of the protocol suggests that these drops occurred because of issues not necessarily pertaining to the design process. Despite the low number of moves and the length of the protocol, significant fixation appears to have occurred only in this area, symbolized by the substantial drop in entropy.

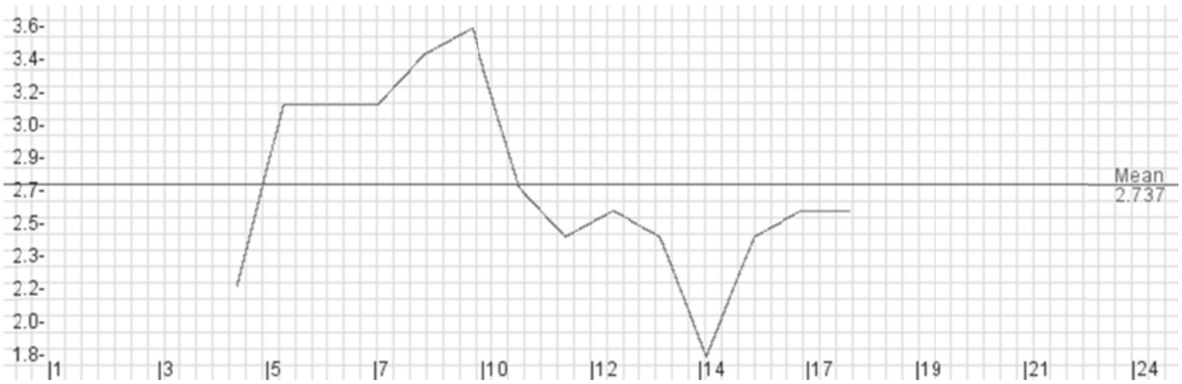


Figure 41. Horizonlinks entropy for augmented reality participant 5.

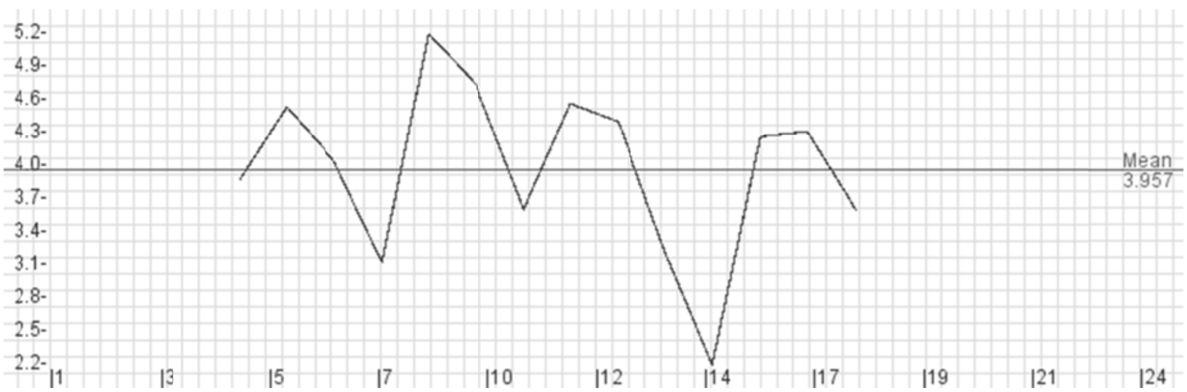


Figure 42. Forelinks entropy for augmented reality participant 5.

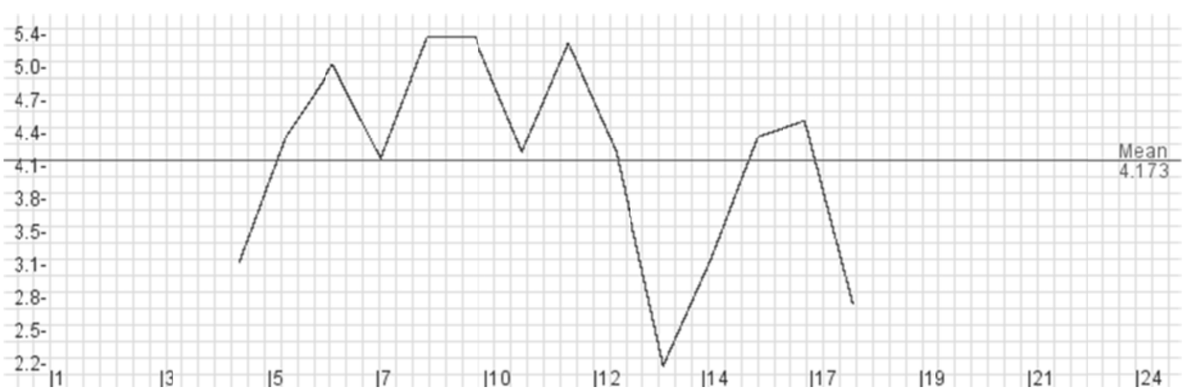


Figure 43. Backlinks entropy for augmented reality participant 5.

Virtual reality participant 1. The linkograph and descriptive statistics for VR participant 1 are shown in Figure 44 and Table 11.

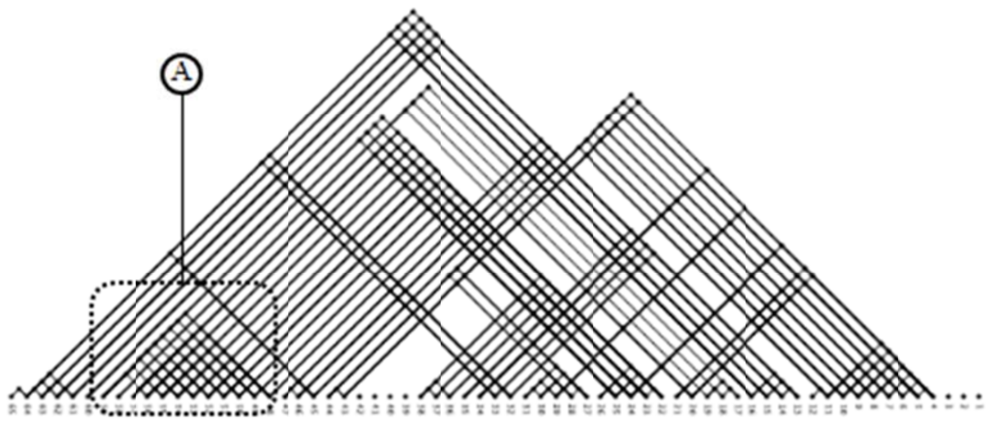


Figure 44. Linkograph for the design protocol of virtual reality participant 1.

Table 11

Descriptive Statistics for Virtual Reality Participant 1

Variable	Statistic
Total Moves	65
Total Links	264
Link Ratio	4.06 per move
Forelink Entropy	27.01
Backlink Entropy	34.897
Horizonlink Entropy	23.883

At first glance, what is unique in this linkograph is that the backlink entropy (Figure 47) is higher than the forelink (Figure 46) and horizonlink (Figure 45) entropies, which suggests there were few opportunities for novel ideas to occur in the protocol as a whole. This is also suggestive of fixation occurring during the design process. However, the occurrence of fixation needs to be analyzed within the design protocol to understand how and why it occurred. The linkograph illustrates that the majority of the design process remains below the mean forelink entropy level. The design process does not start with a high entropy level. Entropy levels drop from move 30 and remain below the mean entropy level except for moves 51 to 55 and 61 to 64. After move 30, the discussion appears to focus more on the visitor chair/couch, and the design is revolving around that one particular idea.

21 Then place these…I'm gonna do the couch for the visiting seat

22 so if there is more than one person present for accounting services they will have an area to sit

23 I move it out to the center of the room and still in line with the desk

30 Move it over by the desk

31 And it looks pretty basic

32 I think it needs something else to make it look a little more interesting

34 that's one of the problems or one of the things I'm not liking about it…

35 so if we put the cabinets back over by the desk,

36 if we scoot the couch back and put it more of an angle as well

37 Can I have more…the one orange chair? Just one

There are also saturated patterns as mentioned in some of the AR protocols (marked as “A”). Saturation is an indicator of fixation.

The linkograph also reveals some saturated links that are suggestive of fixation. Again, entropy dramatically drops after move 53 as the discussion still revolves around the guest chair, which is a clear indication of fixation.

> 53 Ok we are going to try using the chair instead because the couch is huge
>
> 54 umm… so with the chair we have more options in terms of client being closer to the accountant
>
> 55 We can try rotating the chair

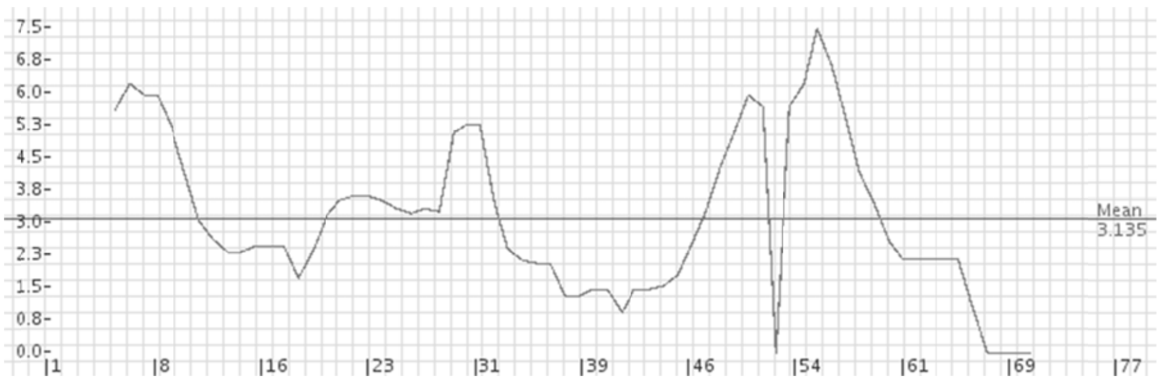


Figure 45. Horizonlinks entropy for virtual reality participant 1.

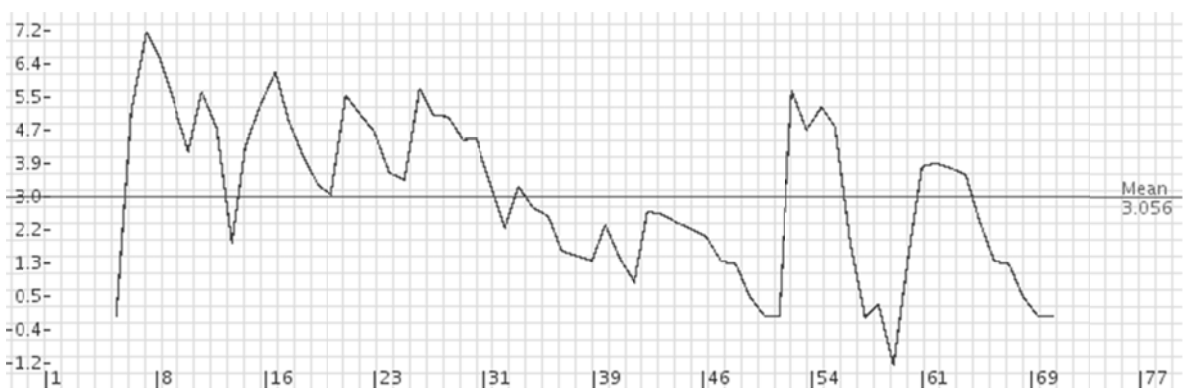


Figure 46. Forelinks entropy for virtual reality participant 1.

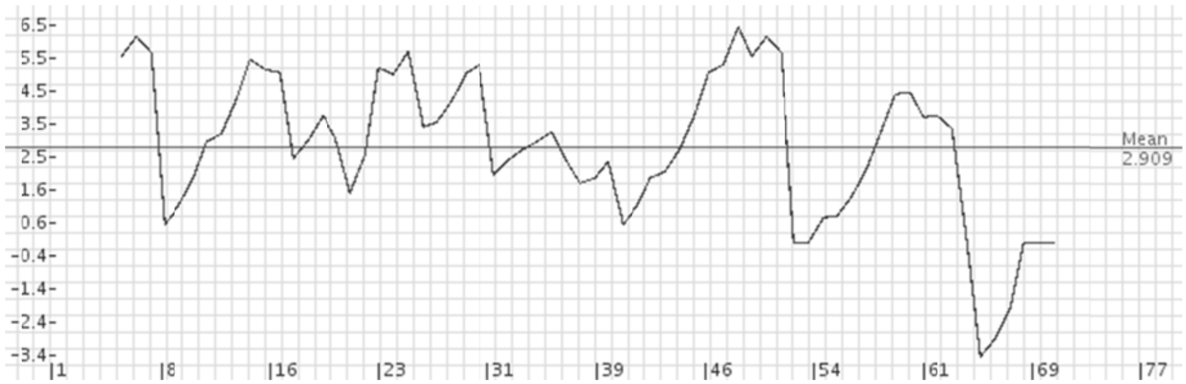


Figure 47. Backlinks entropy for virtual reality participant 2.

Virtual reality participant 2. The linkograph and descriptive statistics for VR participant 2 are shown in Figure 48 and Table 12.

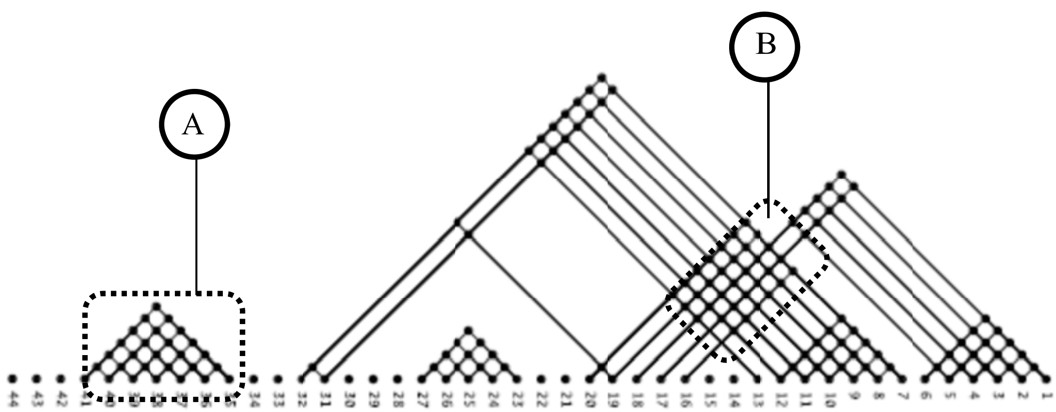


Figure 48. Linkograph for the design protocol of virtual reality participant 2.

Table 12

Descriptive Statistics for Virtual Reality Participant 2

Variable	Statistic
Total Moves	44
Total Links	122
Link Ratio	2.77 per move
Forelink Entropy	13.724
Backlink Entropy	15.050
Horizonlink Entropy	11.077

Again, in this linkograph the backlink (Figure 51) entropy is higher than the forelink (Figure 50) and horizonlink (Figure 49)entropies which suggests that the opportunity for novel ideas was low in the protocol as a whole. This is also suggestive of fixation occurring during the design process. Multiple instances of saturated paterns were observed in the linkograph (marked as A and B). The forelink entropy suggests that only two-thirds of the entropy is above mean entropy levels. The horizonlink entropy is lower than the forelink and backlink entropy levels, which suggests few opportunities for incubation of ideas. However, the there are some prominent drops in entropy.

Despite the training, the participant was having difficulties with the control mechanism.

9 Concentrating on rotating again

10 I was rotating the second storage solution to…

11 so I could see...them better to see…to see

12 which one is better to use…I am still working on that

13 I also keep clicking for the options to go away

14 What do you call those…the axiles

15 I keep clicking them off not on purpose though

The drops in entropy also may be affected by design ideas revolving around a single idea.

35 Do you have any more information about the desk chairs that he selected?

36 Like ergonomical features if they are easy to fit…adjust to fit the users need?

37 Well I’m going to go with the one with the arms

38 because it is always better to have arms on the chair than not.

39 Unless they are at the completely just wrong height

40 but since it is Herman Miller they probably didn’t make the chair poorly.

41 They probably took into consideration well the correct arm height

42 I can’t tell if everything is rotated correctly

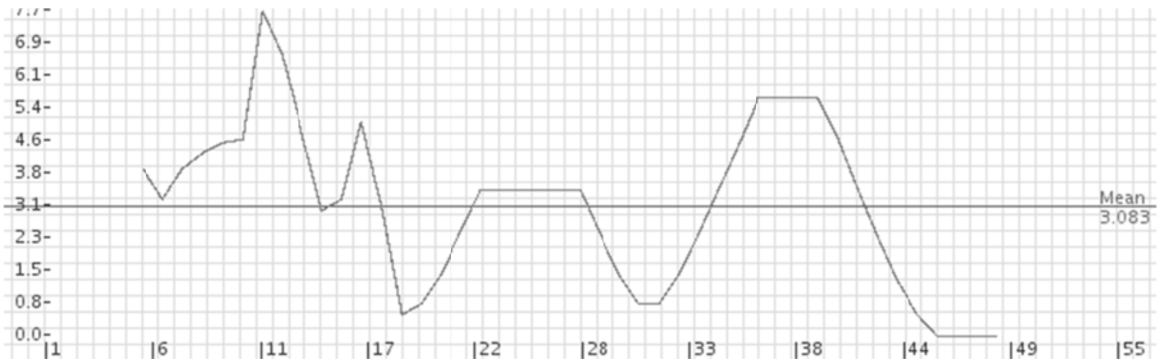


Figure 49. Horizonlinks entropy for virtual reality participant 2.

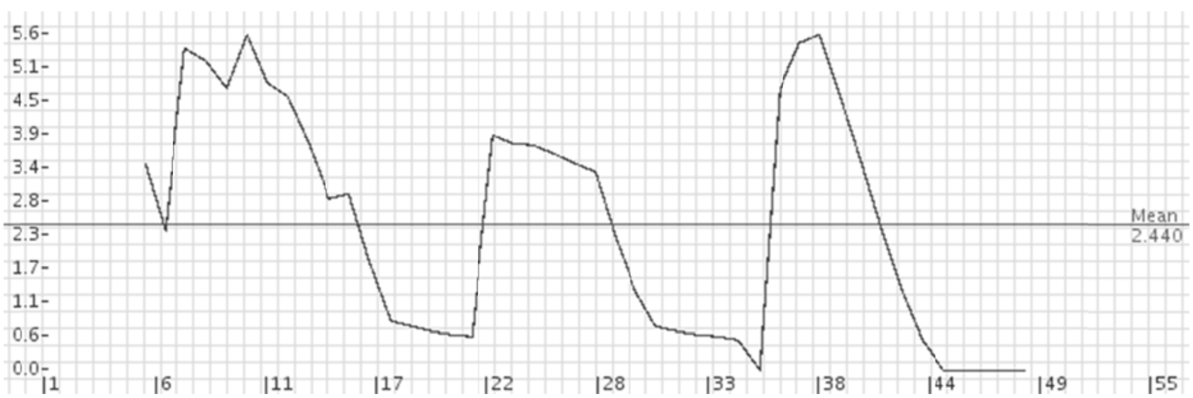


Figure 50. Forelinks entropy for virtual reality participant 2.

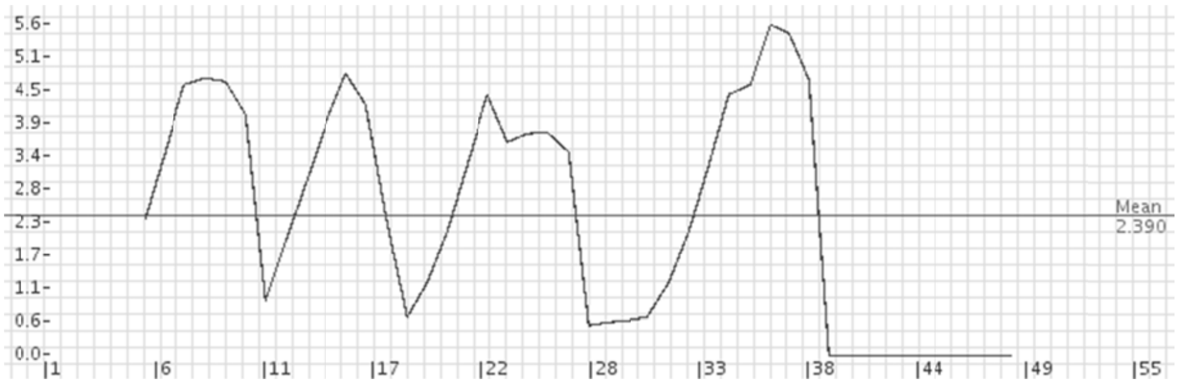


Figure 51. Backlinks entropy for virtual reality participant 2.

Virtual reality participant 3. The linkograph and descriptive statistics for VR participant 3 are shown in Figure 52 and Table 13.

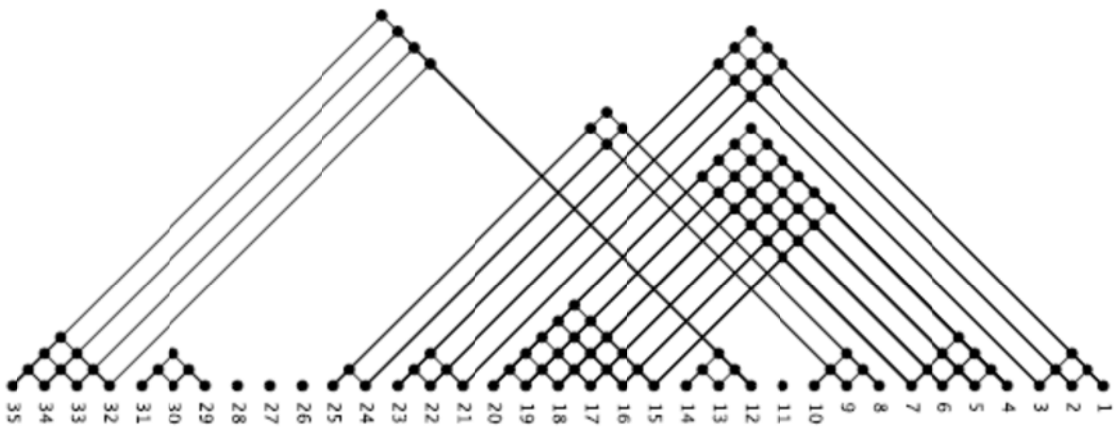


Figure 52. Linkograph for the design protocol of virtual reality participant 3.

Table 13

Descriptive Statistics for Virtual Reality Participant 3

Variable	Statistic
Total Moves	35
Total Links	84
Link Ratio	2.4 per move
Forelink Entropy	14.783
Backlink Entropy	15.956
Horizonlink Entropy	11.009

Again, in this linkograph the backlink entropy (Figure 55) is higher than the forelink (Figure 54) and horizonlink (Figure 53) entropies, which suggests that the opportunity for novel ideas was low in the protocol as a whole. This is also suggestive of fixation during the design process through saturation. The forelink entropy suggests that only half of the entropy is above mean entropy levels. The horizonlink entropy is lower than the forelink and backlink entropy levels, which suggests few opportunities for incubation of ideas. Unlike most other linkographs, the entropy level remains above the mean level even at the end of the design process.

When the participant considers the overall design and relates it to other design elements, the entropy levels seem to increase.

15 Ok I am rotating the desk

16 and I'm going to have it facing the doorway

17 but over a little bit so that he doesn't…well I'm just kidding hmm

18 maybe I will rotate it this way and have it facing that wall.

There seem to be two major fixation periods in the design process. The larger drop in entropy occurs after move 20.

21 Then this office chair is gonna go behind because the desk …

22 because that’s where office chairs goes…

23 oops…ok and we put that close to the desk

24 maybe along the back wall facing his desk…

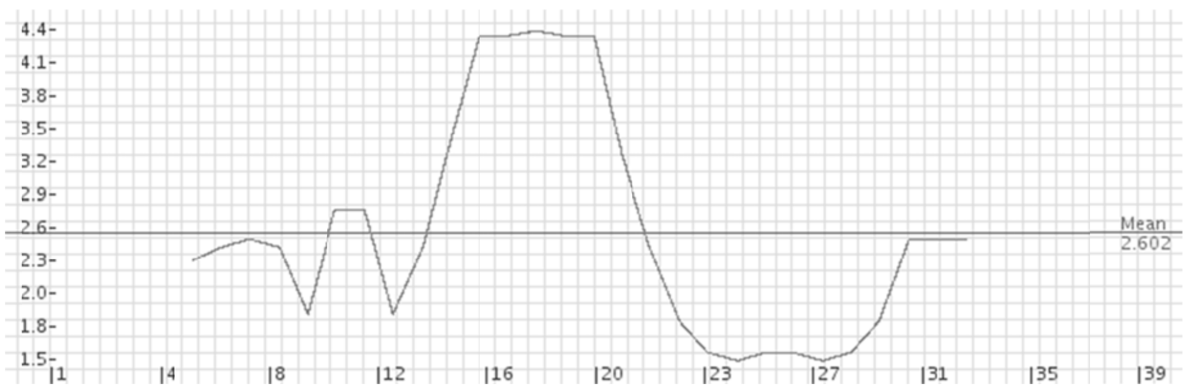


Figure 53. Horizonlinks entropy for virtual reality participant 3.

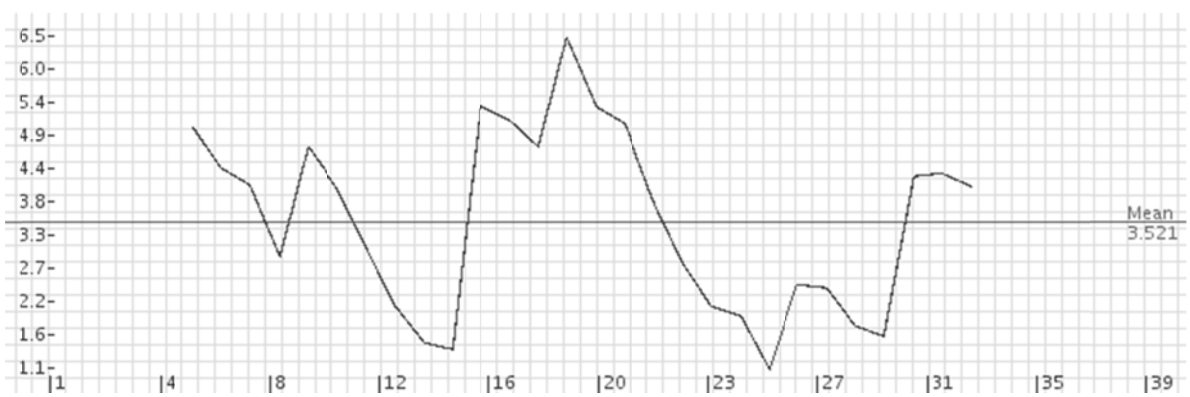


Figure 54. Forelinks entropy for virtual reality participant 3.

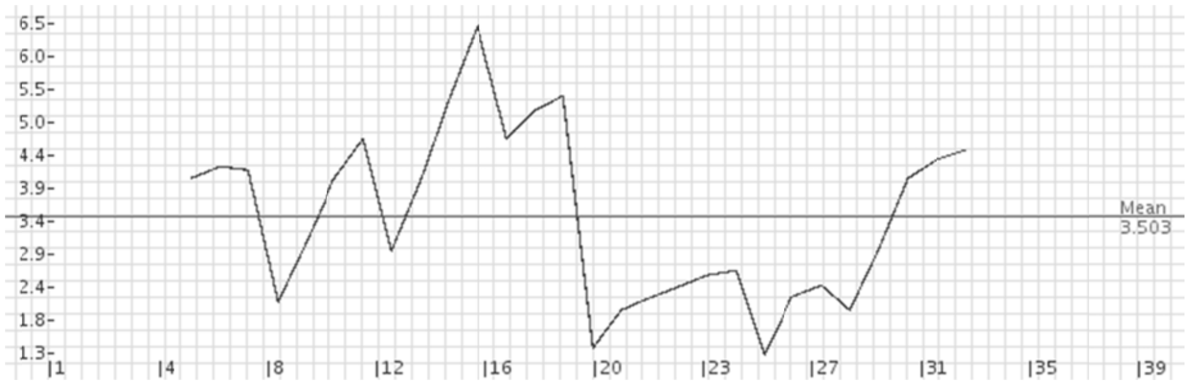


Figure 55. Backlinks entropy for virtual reality participant 3.

Virtual reality participant 4. The linkograph and descriptive statistics for VR participant 4 are shown in Figure 56 and Table 14.

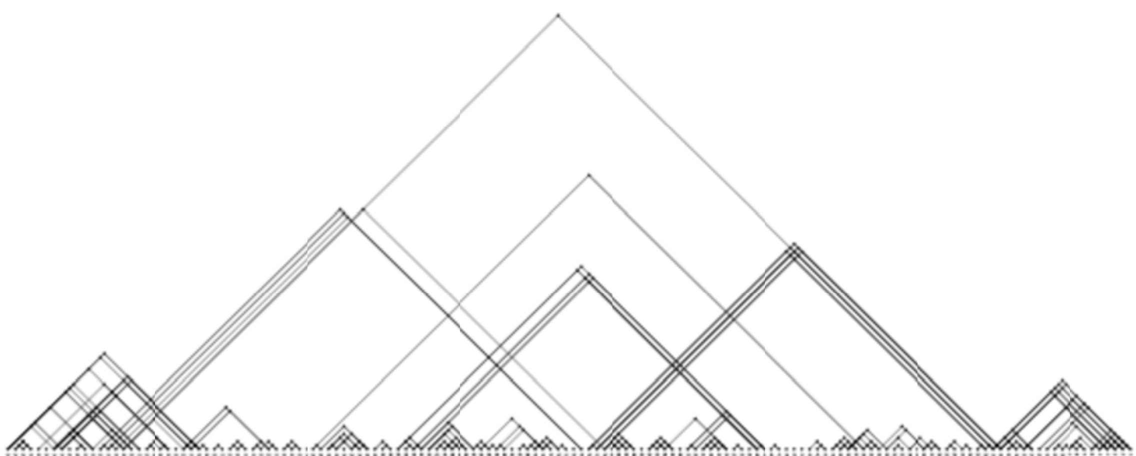


Figure 56. Linkograph for the design protocol of virtual reality participant 4.

Table 14

Descriptive Statistics for Virtual Reality Participant 4

Variable	Statistic
Total Moves	148
Total Links	226
Link Ratio	1.53 per move
Forelink Entropy	25.293
Backlink Entropy	24.842
Horizonlink Entropy	7.372

In this linkograph, the backlink forelink entropy (Figure 58) is slightly higher than the backlink (Figure 59) entropy (by 0.45). The overall horizonlink entropy (Figure 57) is very low at 7.37, which again suggests few opportunities for incubation of ideas. The protocol itself is lengthy compared to the other design protocols, with 148 moves.

There is a major drop in entropy appearing from move 33 to 46. During this time period the participant appears to focus on single design elements.

34 are these lateral files over here?

35 do they have filing? ok then we are going to go with the clean look

36 and it matches the chairs,

37 I'm actually going to choose this one,

38 I feel the legs on this one match.

39 Ok this one's better,

40 this one has a small circle around to rotate it

41 I find it easier to maneuver.

42 However I grabbed the outside circle...

Apart from this significant drop, the design process seems to fluctuate equally around the mean forelink entropy. There appear to be no significantly high entropy levels similar to the drop in entropy that was observed around move 33. From move 25 to 30 the forelink entropy appears to spike. This is possibly because of the rapid change in related ideas.

25 I grabbed the person visiting the offices furniture first.

26 now I'm choosing the...

27 actually...I'm going to stop here...

28 the desk is for an accountant...correct?

29 I like the other desk more

30 but I will choose this desk for the function.

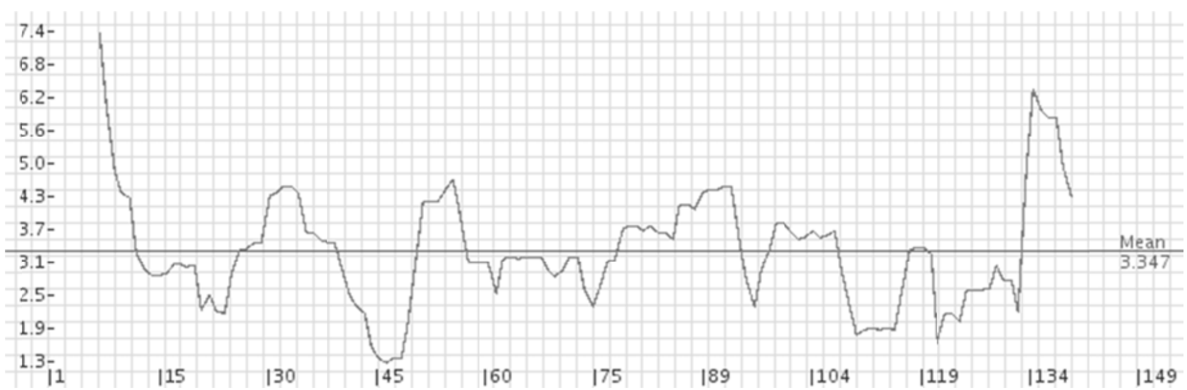


Figure 57. Horizonlinks entropy for virtual reality participant 4.

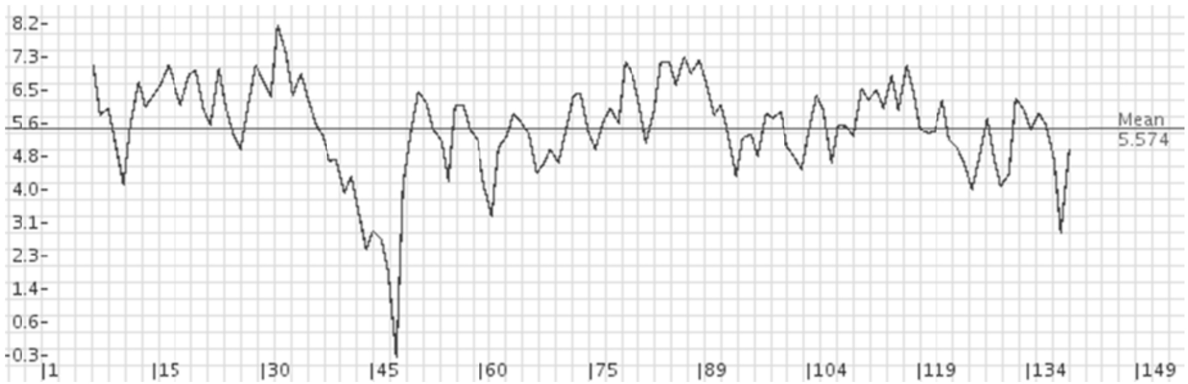


Figure 58. Forelinks entropy for virtual reality participant 4.

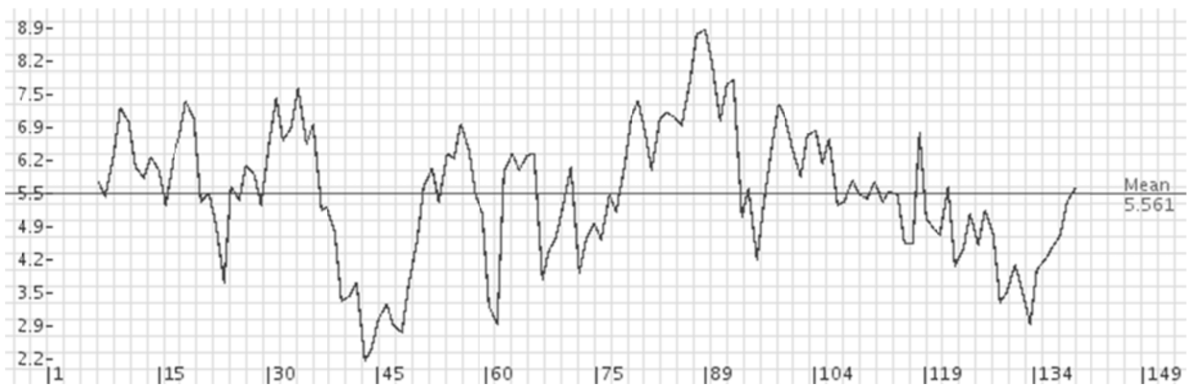


Figure 59. Backlinks entropy for virtual reality participant 4.

Virtual reality participant 5. The linkograph and descriptive statistics for VR participant 5 are shown in Figure 60 and Table 15.

.

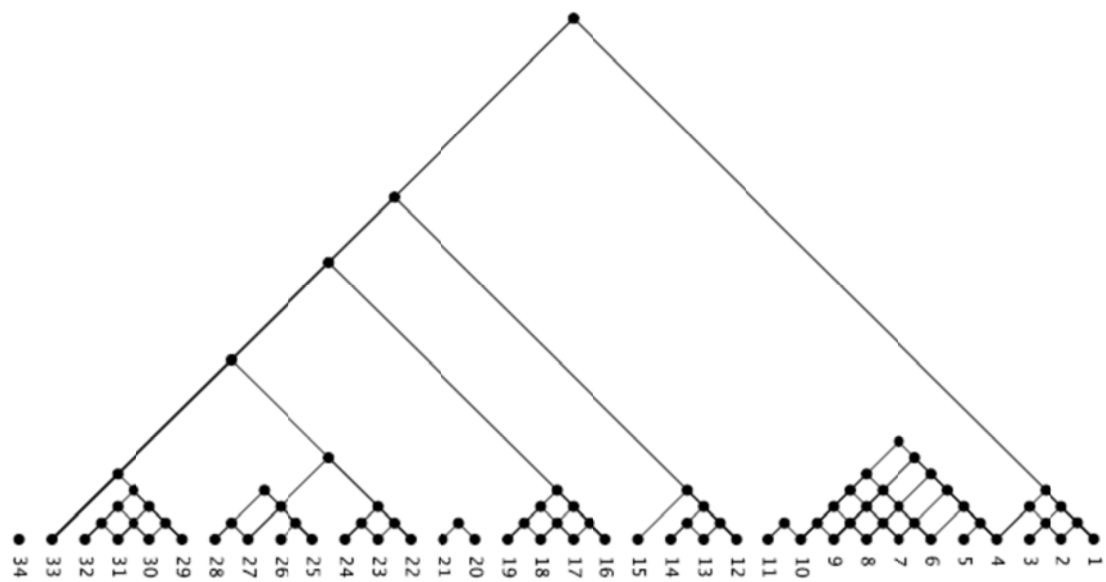


Figure 60. Linkograph for the design protocol of virtual reality participant 5.

Table 15

Descriptive Statistics for Virtual Reality Participant 5

Variable	Statistic
Total Moves	34
Total Links	52
Link Ratio	1.53 per move
Forelink Entropy	12.503
Backlink Entropy	13.509
Horizonlink Entropy	5.769

As seen in almost all of the other linkographs in the VR environment, again in this linkograph the backlink (Figure 63) entropy is higher than the forelink (Figure 62) and horizonlink (Figure 61) entropies, which suggests that the opportunity for novel ideas was low in the protocol as a whole. This is also suggestive of fixation occurring during the design process. The horizonlink entropy is lower than the forelink and backlink entropy levels, which suggests fewer opportunities for incubation of ideas. Unlike most other linkographs, the entropy level remains above the mean level even at the end of the design process. Inspection of the linkograph suggests that the design process is segmented.

When the participant considers the overall design and relates it to other design elements, the entropy levels seem to increase. The design process starts with a higher forward entropy level and continues to increase. However, entropy levels drop after the seventh move when the participant begins discussing the characteristics of the environment without necessarily focusing on the design. From move nine onwards there is a large drop in entropy, which indicates opportunity for fixation.

After move 14, the forelink entropy levels fluctuate around the mean. Unusually, at the end of the design process the forelink entropy level increases to above the mean entropy level.

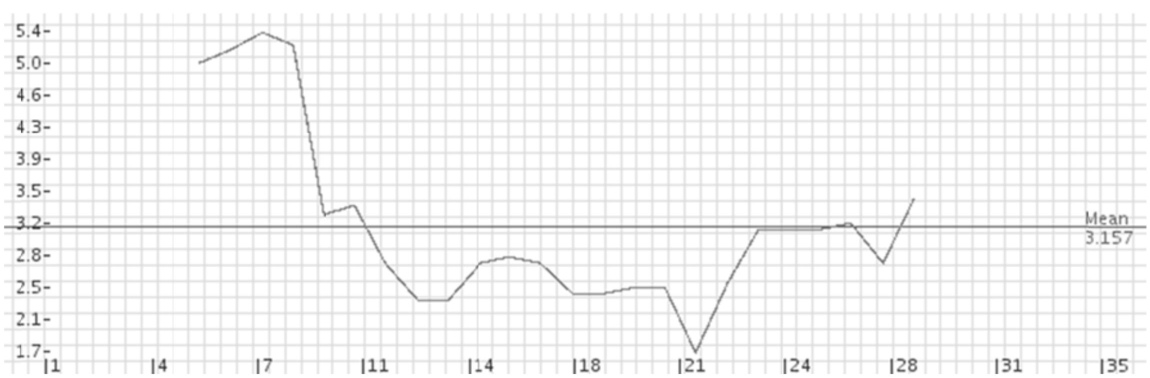


Figure 61. Horizonlinks entropy for virtual reality participant 5.

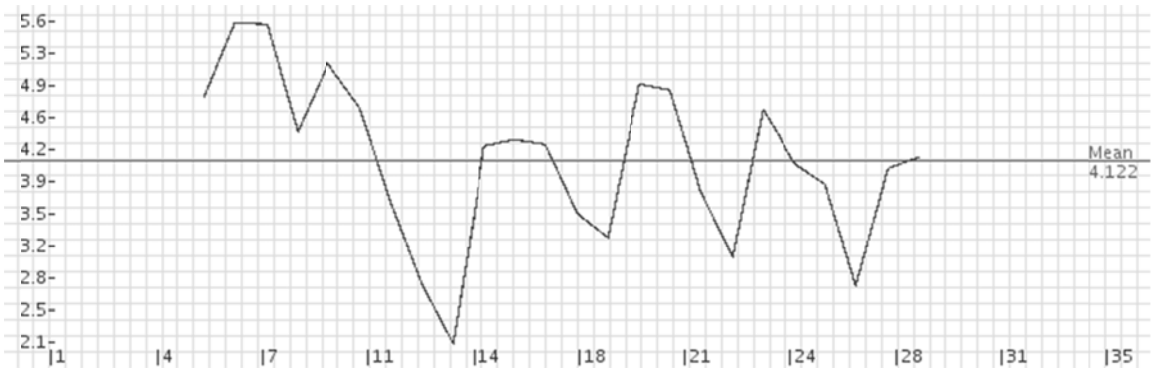


Figure 62. Forelinks entropy for virtual reality participant 5.

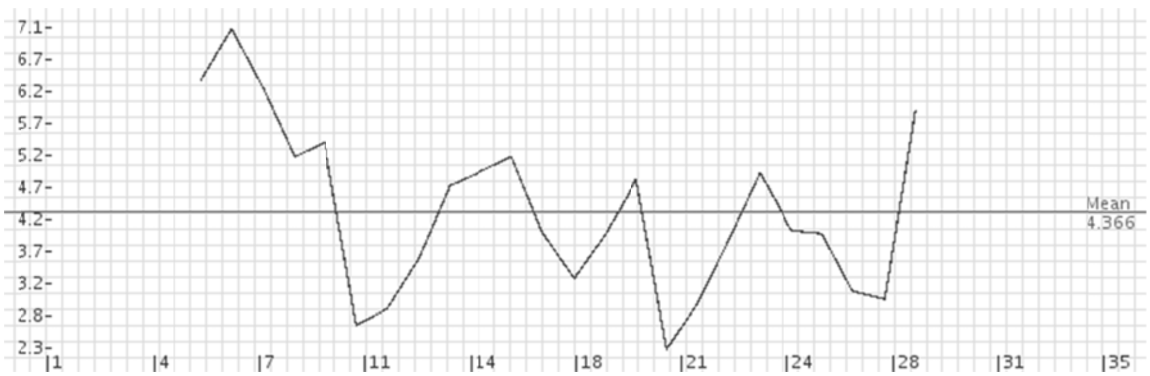


Figure 63. Backlinks entropy for virtual reality participant 5.

Calculating Overall Entropy Levels

Two strategies were used to compare overall entropy levels between the AR and VR interfaces. The first strategy was to compare individual entropies of the participants in each interface type, and the second was to compare the mean entropies between the two interfaces. Previous studies on entropy comparisons have used the same methods (Kan et al., 2007).The overall entropy levels in the two groups are provided in Table 16.

Table 16

Overall Entropy Levels across the Augmented Reality and Virtual Reality Interface Types

Participant	AR Forelink Entropy (FE)	AR Backlink Entropy (BE)	AR Horizonlink Entropy (HE)	VR Forelink Entropy (FE)	VR Backlink Entropy (BE)	VR Horizonlink Entropy (HE)
1	16.43	14.18	10.34	27.01	34.9	23.88
2	17.30	25.08	25.76	13.72	15.05	11.08
3	20.47	17.23	9.93	14.78	15.96	11.01
4	13.71	15.85	10.58	25.29	24.84	7.37
5	11.23	10.32	9.15	12.50	13.51	5.77

Forelink entropy (FE) in three out of the five participants in the AR environment is greater than backlink entropy. In the VR environment, one out of five participants' FE levels was greater than the backlink entropy. Overall horizonlink entropy levels were low in both environments compared with the backlink entropy levels. The horizonlink entropy levels are associated with the opportunity for incubation but because of the short time span of the simple design problem, the horizonlink entropy does not provide adequate opportunities for incubation of ideas.

When FE is greater than the backlink entropy (BE), the design process is considered to have fewer fixation episodes and therefore is considered to be more creative. In this study, 60% of the AR participants had larger FE as compared to BE, while 20% of the VR participants had larger FEs as compared to BEs. The differences in FE and BE (FE-BE) are provided in Table 17.

Table 17

The Difference between Forelink Entropy and Backlink Entropy (FE-BE)

Participant	AR	VR
1	2.25	-7.89
2	-7.78	-1.33
3	3.24	-1.18
4	-2.14	.45
5	.91	-1.01
Mean	-.704	-2.192

If the overall entropy was considered for all five participants, then the above table suggests that overall BE was higher in both groups. There is a clear difference in entropy between the AR and VR environments. In the AR environment, overall FE was higher than BE as compared to the VR environment.

Link ratio or link index is the ratio between the number of links and the number of moves (Goldschmidt, 1992; Kan et al., 2007). Kan et al. (2007) stated that link ratios are indicators of design productivity and are positively related to creativity. Cai, Do, and Zimring (2010) stated that the linkographs of more creative design processes would display higher link ratios. In this study, the link ratios of the design processes between the two media types is shown in Table 18. The mean values of link indexes for the two types of media show that AR has a higher link index. Even though the mean entropies do not show so much of a difference, AR had more link ratios than VR except for case 1 which, suggests that the design processes of the participants that used the AR interface were more creative.

Table 18
Link Ratios in the Protocols

Participant	AR	VR
1	2.19	4.06
2	4.06	2.77
3	2.76	2.4
4	1.7	1.53
5	1.74	1.53
Mean	2.49	2.46

Statistical tests are not conducted in most studies using entropy calculations and this type of mean comparisons are used. For example, Kan et al. (2007) calculated the entropy and link indexes between two groups and compared the averages between them. Statistically significant tests are not conducted in protocol analysis mainly due to the low number of participants. However in certain cases, the number of moves can be used as the unit of analysis to conduct statistical tests, as shown in Chandrasekera et al. (2013).

Cognitive Load

The pencil and paper version of the NASA TLX was administered to all participants. The participants were provided with a list of a series of pairs of rating scale titles (e.g., effort vs. mental demand) and were asked to circle which of the items was more important to their experience of workload in the design project task they had just performed. The participants were given 15 such comparisons. The results were recorded in front of each rating scale using the sources of workload tally sheet (see Appendix I). The total count was checked to ensure that it was 15. Raw ratings were obtained from the NASA TLX questionnaire presented to the participants. Using the weighted rating worksheet, the weight obtained from the workload tally sheet was multiplied by the raw rating to obtain the adjusted rating for each rating scale. These adjusted ratings were summed to obtain a total adjusted rating and the total was divided by 15 to obtain the weighted rating for each participant. The NASA TLX score is documented below in two steps. First the cognitive load of the 10 subjects selected for protocol analysis (in two groups) are documented (see Table 19), then the cognitive load of all subjects are documented.

Table 19
Overall Cognitive Load Measurement

Participant	VR	Participant	AR
1(VR)	3.0	1(AR)	2.33
2(VR)	3.4	2(AR)	3.06
3(VR)	2.67	3(AR)	2.46
4(VR)	5.67	4(AR)	2.2
5(VR)	2.27	5(AR)	2.4
Mean	3.402	Mean	2.49

For the 10 participants who were selected for protocol analysis the observed mean cognitive load in the AR interface was lower compared to the VR interface. For exploratory purposes, an independent samples *t*-test was conducted. The results revealed that the differences were not significant between the two interfaces, VR (M = 3.4, SD = 1.334) and AR (M = 2.5, SD = 0.33); $t(8) = 1.483$, $p = 0.176$). Statistical significance was not expected due to the low number of participants.

Because the measurement of cognitive load did not depend on the protocol analysis, cognitive load of all 30 participants was calculated and compared between the VR and AR interfaces. An independent samples t-test found a statistically significant difference between the two interface types, VR (M = 3.06, SD = 1.32) and AR (M = 2.2, SD = 0.83); $t(28) = 2.096$, $p = 0.045$). The results suggest that the cognitive load in the AR interface was lower than in the VR interface.

Epistemic Action

The characteristics of the action were used to categorize epistemic actions in the design process as N (New actions), Rr (Revisit rotate action), and Rm (Revisit move action). The N-actions were not considered as epistemic actions as they were the initiating move and were equal as well as pre-determined in both AR and VR interfaces. Statistical analyses were conducted for the Rr and Rm actions. In all design sessions, the N code was assigned to the first five moves of adopting a design element into the design. Hence, in all design sessions there were five N codes. The unit of analysis was the number of moves rather than number of participants; there were 205 moves for AR and 326 moves for VR. The proportion of the epistemic actions were calculated by dividing the number of total moves with epistemic actions (Rr or Rm) by the total number of moves in the media type (see Table 20).

Table 20

Proportion of Epistemic Actions in the Protocol

	Revisit Rotate	Revisit Move	New Action
Augmented Reality	0.14	0.19	0.19
Virtual Reality	0.05	0.14	0.08

Pearson chi-square tests were conducted to analyze the association between Rr actions, Rm actions, and total epistemic actions within the design process. First, the proportion of Rr actions based on the overall number of moves in the design process between VR and AR was observed and analyzed (see Table 21).

Table 21

Number and Proportion of Revisit Rotate Actions in Virtual Reality and Augmented Reality

Media Type (AR/VR) * Y/N Crosstabulation				
Media Type	Count	Y	N	Total
		.00	1.00	
Virtual Reality	Observed	18	308	326
	Expected	28.9	297.1	326.0
	% within Virtual Reality	5.5%	94.5%	100.0%
Augmented Reality	Observed	29	176	205
	Expected	18.1	186.9	205.0
	% within Augmented Reality	14.1%	85.9%	100.0%
Total	Observed	47	484	531
	Expected	47.0	484.0	531.0
	% within All Media	8.9%	91.1%	100.0%

The type of user interface and Rr actions were strongly associated ($\chi^2 = 11.605$, $p = 0.001$; see Table 22). A significantly higher proportion of Rr actions were observed in the AR environment (14.1%) than the VR environment (5.5%).

Table 22

Chi-Square table for Revisit Rotate Actions

Chi-Square Test					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.605[a]	1	.001		
Continuity Correction	10.560	1	.001		
Likelihood Ratio	11.242	1	.001		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.583	1	.001		

Note: The number of valid cases is 531. No cells have an expected count less than 5. The minimum expected count is 18.15. The continuity correction is for a 2X2 table.

Second, the proportion of Rm actions based on the overall number of moves in the design process between VR and AR were also observed and analyzed. The results are shown in Tables 23 and 24.

Table 23

Number and Proportion of Revisit Move Actions in Virtual Reality and Augmented Reality

Media Type (AR/VR) * Y/N Crosstabulation				
Media Type	Count	Y .00	N 1.00	Total
Virtual Reality	Observed	47	279	326
	Expected	52.8	273.2	326.0
	% within Media	14.4%	85.6%	100.0%
Augmented Reality	Observed	39	166	205
	Expected	33.2	171.8	205.0
	% within Media	19.0%	81.0%	100.0%
Total	Observed	86	445	531
	Expected Count	86.0	445.0	531.0
	% within Media	16.2%	83.8%	100.0%

Table 24

Chi-Square Table for Revisit Move Actions

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.968[a]	1	.161		
Continuity Correction[b]	1.643	1	.200		
Likelihood Ratio	1.940	1	.164		
Fisher's Exact Test				.183	.101
Linear-by-Linear Association	1.965	1	.161		

Note: The number of valid cases is 531. No cells have an expected count less than 5. The minimum expected count is 33.20. The continuity correction is for a 2X2 table.

The type of user interface and Rm actions were not associated (χ^2 = 1.968, *p* = 0.161). Even though more Rm actions were observed in the AR environment (19%) than in the VR environment (14.4%), the difference is not significant.

Third, the proportion of overall number of epistemic action moves (Rr actions plus Rm actions) based on the overall number of moves in the design process between VR and AR were observed and analyzed (see Tables 25 and 26).

Table 25

Overall Epistemic Actions in Virtual Reality and Augmented Reality

Media Type (AR/VR) * Y/N Crosstabulation				
Media Type	Count	Y .00	N 1.00	Total
Virtual Reality	Observed	65	261	326
	Expected	81.7	244.3	326.0
	% within Media	19.9%	80.1%	100.0%
Augmented Reality	Observed	68	137	205
	Expected	51.3	153.7	205.0
	% within Media	33.2%	66.8%	100.0%
	Total Observed	133	398	531
	Total Expected	133.0	398.0	531.0
	% within All Media	25.0%	75.0%	100.0%

Table 26

Chi Square Table for Overall Epistemic Actions

Chi-Square Tests					
	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.738[a]	1	.001		
Continuity Correction	11.044	1	.001		
Likelihood Ratio	11.535	1	.001		
Fisher's Exact Test				.001	.000
Linear-by-Linear Association	11.716	1	.001		

Note: The number of valid cases is 531. No cells have an expected count less than 5. The minimum expected count is 51.35. The continuity correction is for a 2X2 table.

The type of user interface and overall epistemic action moves were strongly associated ($\chi^2 = 11.738$, $p = 0.001$). There was a significantly higher proportion of overall epistemic action moves in the AR environment (33.2%) than the VR environment (19.9%).

As suggested by Kim and Maher (2008), the designers reduced the amount of working memory by performing “revisited” modeling actions. The significance of these epistemic actions supports the idea that the trial-and-error type movements seen in the AR design sessions are an indicator of epistemic payoff. This result indicates that designers’ cognitive load might have been reduced in the AR interface by their use of epistemic actions.

Summary of Findings

In this section the following research questions were investigated:

- How does interface type affect epistemic actions?
- How does interface type affect cognitive load?
- How does interface type affect fixation?

Hypotheses H1-H4 (Chapter 3) were tested.

H1: The type of user interface used in design problem solving affects a designer's use of design action in ways of epistemic actions. In all design sessions the "New action" was assigned to the first five moves of adopting a design element into the design. Therefore, there were five N codes in all design sessions. Pearson chi-square tests analyzed whether the design process impacted the relative use of Rr actions (Revisit rotate action), Rm actions (Revisit move action), and total epistemic actions. The Rr epistemic actions occurred at a significantly higher proportion in the AR interface than the VR interface. However, even though the mean value for Rm was higher in the AR interface, the type of media did not significantly affect Rm epistemic actions. Total epistemic actions occurred at a significantly higher rate in the AR interface as compared to the VR interface.

The significance of these epistemic actions is that the trial-and-error type movements seen in the AR design sessions are an indicator of epistemic payoff. The null hypothesis for H1 was rejected. The conclusion is that AR provided a more conducive environment for epistemic actions. This finding was statistically significant for the Rr type of epistemic actions as well as the total epistemic actions. As suggested by Kim and Maher (2008), the designers reduced the amount of exerted working memory by performing “revisited” modeling actions. This result indicates that designers’ cognitive load might have been reduced by epistemic actions in the AR interface.

H2: The type of user interface used in design problem solving affects the cognitive load required by the user interface. The initial calculations of cognitive load of the 10 participants who were selected for protocol analysis revealed that the cognitive load differences were not significant. However, the sample size of 10 did not provide enough power in the experiment to yield significant results. Because the measurement of cognitive load did not depend on the protocol analysis, the cognitive loads of all 30 participants were calculated and compared between the VR and AR interfaces. Independent samples t-test found a statistically significant difference between the two interface types. The results suggest that the cognitive load in the AR interface was lower than in the VR interface. The null hypothesis for H2 was rejected and the conclusion is that the cognitive load was significantly less in the AR interface as compared to the VR interface.

H3: The type of user interface used in design problem solving affects fixation in design problem solving process. Forelink entropy was greater than the backlink entropy for three out of the five participants in the AR interface. In the VR interface, only one participant’s forelink entropy level was greater than the backlink entropy. Overall horizonlink entropy levels were low in both interfaces compared with backlink entropy levels. In this study 60% of the AR participants had larger forelink entropies as compared to backlink entropies, while 20% of the VR participants had larger forelink entropies as compared to backlink entropies. When overall forelink and backlink entropies were considered, there was a clear difference in entropy between the AR and

VR interfaces. In the AR interface, overall Forelink entropy was higher than backlink entropy as compared to VR.

Furthermore, the mean value for link indexes in the AR interface was higher than the link indexes in the VR interface, suggesting that the design processes of the participants that used the AR interface were more creative. The null hypothesis for H3 was rejected and the conclusion is that the VR interface provided a more conducive environment for fixation (as identified in the linkograph).

H4: The type of user interface used in design problem solving affects creativity in design process. Considering all of the above findings, the overall conclusion is that epistemic actions reduce fixation in the design process as signified by the high forelink entropy level. Epistemic actions reduce cognitive load and fixation in the design process. The null hypothesis for H4 was rejected.

Chapter 5. Part 2- Tangibility in interfaces and Learning Style

Objectives and Hypotheses

The main objective in this section is to identify the effect of interface type on the learner preferences of the participants. Learner preferences of the participants were assessed using the VARK learning styles inventory, which classifies user preferences as visual, auditory, read/write, and kinesthetic.

Previous studies have shown that creativity is affected by intrinsic motivation. Furthermore, intrinsic motivation has been shown to be driven by the Perceived Ease of Use (PEU) of an assistive technology. PEU is one of the factors emphasized in the Technology Acceptance Model (TAM). In order to determine how the interface type affects learner preference, Perceived Ease of Use (PEU), Perceived Usefulness (PU), and Intention to Use (IU) were compared between the two interface types for two learning styles; visual and kinesthetic learning styles.

The following research questions and hypotheses were investigated with a series of statistical tests.

RQ2: How does type of user interface (AR/VR) and learner preference affect the creative design process?

RQ2.1: How does interface type affect technology acceptance?

RQ2.2: How does learner preference interact with type of user interface to affect technology acceptance?

The hypotheses for this section are as follows.

- H5: The type of user interface used in design problem solving affects the PEU of the user interface.
- H6: The type of user interface used in design problem solving affects the PU of the user interface.
- H7: The type of user interface used in design problem solving affects the IU.
- H8: The learner preference of the user moderates the PEU of the user interface.
- H9: The learner preference of the user moderates the PU of the user interface.
- H10: The learner preference of the user moderates the IU of the user interface.

Analysis and Discussion

Prior to the design experiment, 30 junior and senior college students who participated in the study completed a survey about their learner preferences. The 30 students were randomly assigned to the two interface types. The distributions of gender, age, and academic background between the two interface types are shown in Table 27.

Table 27
Demographics in the Augmented and Virtual Reality Groups

	Gender		Age		Academic Level	
	M	F	18-25	30-35	Senior	Junior
AR	0	15	15	0	6	9
VR	1	14	14	1	8	7

VARK learning styles were used in this study to understand the students' learner preferences rather than to categorize them. The learning style questionnaire was based on the VARK Learning Styles Inventory (Fleming & Mills, 1992), which analyzes students' preferences for visual, aural, read/write and kinesthetic modes. All participants completed the survey.

A posttest survey (see Appendix B) based on the TAM (Davis, 1989) was administered to all 30 participants. The survey focused on comparing PEU, PU, and IU between the interface types (AR and VR). The independent variables in this study were interface type and learner preference. The dependent variables were PEU, PU, and IU.

Multivariate statistical software (SPSS version 20) was used to obtain descriptive statistics and to perform statistical analyses. A series of statistical tests were performed to test the research hypotheses. A one way analysis of variance (ANOVA) was performed to compare the dependent variables (PU, PEU, and IU) between the two interface types. A two-way ANOVA was performed to explain the interaction between interface type and learner preference. To assess the relationship between PU and IU as well as PEU and IU, bivariate correlation coefficients (Pearson's *r*) were computed.

Reliability and Validity of the Instrument

The TAM instrument was adopted from an established TAM scale. The tool measures the subjective perceptions of technology use and has been previously validated in a number of studies (Davis, 1989; Davis, 1993; Dishaw & Strong, 1999; Igbaria, 1993; Igbaria, Schiffman, & Weickowski, 1994). Internal consistency of the measures in the TAM instrument was assessed by Cronbach's alpha (α) computed using SPSS. Cronbach's alpha ranges between 1 and 0, and internal consistency is considered greater as the value approaches 1. In the instrument used in this study, the PEU subscale consisted of nine items ($\alpha = .813$), and the PU subscale consisted of 5 items ($\alpha = .58$). In order to improve the α level for the PU subscale, one item was removed, which improved the Cronbach's α value to .65. DeVellis (1991) stated that an α value of 0.60 to 0.65 is undesirable but acceptable. The IU subscale consisted of two items ($\alpha = .79$).

The VARK questionnaire (Fleming & Mills, 1992) is an established learning style evaluation tool and was used without any modification, so checking the reliability or validity of the tool was not necessary.

Comparison of the Dependent Variables between the Interface Types

A one-way ANOVA analyzed the difference between interface type and the dependent variables. Table 28 shows the descriptive statistics for PEU, IU, and PU by interface type. ANOVA results for PU, IU and PEU are presented Table 29.

Table 28
Descriptive Statistics for the Virtual and Augmented Reality Interfaces

Dependent Variable	Independent Variable	Mean	SD	Skewness		Kurtosis	
				Statistic	Std. Error	Statistic	Std. Error
Perceived Usefulness (PU)	VR	4.83	1.08	-.49	.58	.15	1.12
	AR	5.90	0.60	.54	.58	-1.02	1.12
Behavioral Intention to Use (IU)	VR	4.70	1.33	.18	.58	-.77	1.12
	AR	6.20	0.80	-.77	.58	-.24	1.12
Perceived Ease of Use (PEU)	VR	5.52	0.95	-.85	.58	.96	1.12
	AR	6.23	0.26	.19	.58	-.89	1.12

Note: N = 15

Table 29
ANOVA Summary Table for Interface Type

Dependent Variable	Source	SS	df	MS	F	p
Perceived Usefulness	Between Groups	8.533	1	8.533	11.213	.002
	Within Groups	21.308	28	0.761		
	Total	29.842	29			
Behavioral Intention to Use	Between Groups	16.875	1	16.875	13.979	.001
	Within Groups	33.800	28	1.207		
	Total	50.675	29			
Perceived Ease of Use	Between Groups	3.793	1	3.793	7.804	.009
	Within Groups	13.608	28	0.486		
	Total	17.401	29			

The difference between the two interface types was significant for all three dependent variables: PU, $F(1,28) = 11.21$, $p = .002$); IU, $F(1,28) = 13.979$, $p = .001$); and PEU, $F(1,28) = 7.804$, $p = .009$). All three dependent variable means were significantly higher in the AR interface type, PU: $M = 5.90$, $SD = 0.60$; PEU: $M = 6.23$, $SD = 0.26$; and IU: $M = 6.20$, $SD = 0.80$, compared to the VR interface type, PU: $M = 4.83$, $SD = 1.08$; PEU: $M = 5.52$, $SD = .95$; and IU: $M = 4.70$, $SD = 1.33$.

Comparison of the Dependent Variables between Interface Type and Learner preference

In order to understand the interaction between interface type and learner preference on the dependent variables (PU, PEU and IU), a two-way ANOVA was performed for each of the dependent variables for exploratory purposes. See Table 31.

Table 30

Descriptive Statistics for Perceived Usefulness

Interface Type	Learner Preference	Mean	Std. Deviation	N
VR	Visual	4.25	.50000	3
	Aural	6.08	.52042	3
	Read/Write	4.81	.42696	4
	Kinesthetic	4.94	1.06800	4
	Multimodal	2.50	.	1
AR	Visual	6.15	.54772	5
	Aural	5.67	.14434	3
	Read/Write	5.25	.00000	3
	Kinesthetic	6.42	.80364	3
	Multimodal	5.75	.	1

Table 31

Two-Way ANOVA Summary Table for the Effect of Learner Preference and Interface Type on Perceived Usefulness

Source	SS	df	MS	F	p
Interface Type	10.127	1	10.127	26.849	.000
Learner preference	6.249	4	1.562	4.142	.013
Interaction	7.956	4	1.989	5.273	.005
Error	7.544	20	.377		
Total	893.875	30			

Note. R^2 = .747 and adjusted R^2 = .633

The effect of the interaction between the interface type and learning style on the PU is significant, $F(4,20) = 5.273$, $p < .005$. The main effect for interface type on PU is also significant, $F(1,20) = 26.85$, $p < .001$. Furthermore, the main effect of learner preference on PU is significant, $F(4,20) = 4.142$, $p < .013$.

Table 32

Differences in Perceived Usefulness between Augmented and Virtual Reality Interface by Learner preference

Learner Preference	Mean Difference	SE	*p*
Visual	-1.900*	.449	.000
Aural	.417	.501	.416
Read/Write	-.437	.469	.362
Kinesthetic	-1.479*	.469	.005
Multimodal	-3.250*	.869	.001

*$p < .01$

The pairwise comparisons suggested that the mean PU score was significantly higher in the AR environment than the VR environment for kinesthetic learners. Furthermore, the mean PU was significantly higher in the AR environment than the VR environment for visual learners. For PEU and IU, the interaction between interface type and learner preference was not significant (p = 0.092 and 0.074 for PEU and IU, respectively).

Because the multimodal learner category only had two participants (one for each interface type), the two participants were removed from the data set and the two-way ANOVA was rerun to observe any difference in the results. Removing these two participants made no difference in the results obtained for the interaction between learner style and interface type on PU, PEU, or IU.

Relationships between Perceived Usefulness and Behavioral Intention to Use as well as Perceived Ease of Use and Behavioral Intention to Use

To investigate the relationship of PEU and PU on the IU as suggested by the TAM, bivariate correlations (Pearson's *r*) were calculated. As expected and predicted by the TAM, all PU, PEU, and IU were positively but not strongly correlated (see Table 33).

Table 33
Correlations among Variables

		Perceived Use	Behavioral Intention to Use
Behavioral Intention to Use (IU)	Pearson's r	$.689^{**}$	
	Sig. (2-tailed)	.000	
Perceived Ease of Use (PEU)	Pearson's r	$.480^{**}$	$.589^{**}$
	Sig. (2-tailed)	.007	.001

Note: $N = 30$ ** $p < .001$

Summary of Findings

In this section, two research questions were investigated: How does interface type affect technology acceptance? And How does learner preference interact with the interface type to affect technology acceptance? Hypotheses H5 through H10 were tested.

H5: The type of user interface used in design problem solving affects the Perceived Ease of Use (PEU) of the user interface.

H6: The type of user interface used in design problem solving affects the Perceived Usefulness (PU) of the user interface.

H7: The type of user interface used in design problem solving affects the Intention to Use (IU).

According to results of the ANOVA, the difference between the two interface types was statistically significant for all three dependent variables, PU, IU, and PEU. All three variables had a higher value in the AR interface. The conclusion is that participants found AR to be easier to use and more useful and were more inclined to use it in the future than VR. Null hypotheses for H5-H7 were rejected.

H8: The learner preference of the user moderates the PEU of the user interface.

H9: The learner preference of the user moderates the PU of the user interface.

H10: The learner preference of the user moderates the IU of the user interface.

According to the results of the two-way ANOVA, the interaction between the interface type and learner preference was significant for PU. As expected, the PU score was significantly higher in the AR environment than the VR environment for kinesthetic learners. Contrary to expectations, the mean PU was also significantly higher in the AR environment than the VR environment for visual learners. The null hypothesis for H9 was rejected.

Research has shown that extrinsic motivation for using assistive technology is captured by the PU construct in the TAM (Davis, 1989; Venkatesh & Davis 2000;

Venkatesh & Speier, 2000). Furthermore, Venkatesh, (2000) stated that intrinsic motivation is related to PEU.

PEU is a measurement of intrinsic motivation that enhances the creative design process. PU is a means of measuring extrinsic motivation. For PEU and IU, the interaction between interface type and learner preference was not significant. From these results the conclusion cannot be made that learner preference affects the creative design process in a given interface type. Therefore, the null hypotheses for H8 and H10 were not rejected.

As expected and as proposed in the TAM, this study found positive correlations between IU and PU as well as IU and PEU. This result validates previous results and the methodology used in this study.

Participants rated PU, PEU, and IU higher for the AR interface. The conclusion is that kinesthetic and visual learners found the AR environment more useful than the VR environment.

Chapter 6. Discussion and Implications

Conclusion

The main research question of the study focused on the effect of user interface type (AR and VR) on the creative design process. Tangibility in user interfaces such as AR offers epistemic action that reduces the cognitive load, thereby reducing fixation effects in the design process as compared to other interfaces such as VR (which were defined as WIMP-based interfaces in this study). The main hypothesis of the study was that interface type affects the use of epistemic actions in the creative design process, which in turn would affect fixation and thereby affect the overall creative design process. Furthermore, a relationship was expected between user preference and creativity in the design process when using AR and VR. The AR environment was operationalized as an interface that offered tangible interaction, as compared to VR which functioned within the WIMP paradigm.

Thirty design students participated in an experiment in which they were required to design the interior of an office. Participants were randomly assigned to the AR and VR conditions. Protocol analyses of 10 participants (five in each group) were conducted. Verbal and visual protocols of the design process were recorded, coded, and analyzed. Epistemic actions were identified by coding designers' actions using protocol analysis. Cognitive load of all 30 subjects was measured using the NASA TLX. The entropy levels were calculated in each of the 10 design protocols.

The first important finding is that the number of epistemic actions was higher in the AR interface as compared to the VR interface and that the difference was significant. The higher tangibility of the AR interface as compared to the VR interface seemed to offer more opportunity for epistemic actions when the participants were designing, which may have reduced the cognitive load imposed by the interface.

Second, the study showed that the cognitive load was significantly lower in the AR interface as compared to the VR interface.

Third, forelink entropy was higher than backlink entropy in the AR interface, which indicates a more conducive environment for the creative design process. Furthermore, the VR interface provided a more conducive environment for fixation than the AR interface. In addition, AR had a higher link index than VR, suggesting that the design processes were more creative in the AR interface.

These results suggest that AR interfaces provide a more conducive environment for a productive design process. The differences in entropy levels and the stages where entropy was noticeably high and low in both interfaces support the hypothesis that interface type affects the entropy levels in the design process, thereby suggesting that interface type affects the creative design process. Epistemic actions promoted (or boosted) by the higher tangibility in AR interface appear to reduce cognitive load imposed by the interface, thereby reducing fixation and enhancing the creative design process. Furthermore, these conclusions are supported by results of previous studies in which AR appeared to enhance the design process by reducing fixation (Chandrasekera & Yoon, 2014a) as well as enhancing spatial cognitive skills (Chandrasekera et al., 2012). The results of this study do not suggest that VR should be replaced by AR but do suggest that certain aspects, such as reducing cognitive load of the design process can be enhanced using AR technology.

This study also provided information on how user preference affects the use of different interfaces. The results suggest that participants perceived AR to be easier to use, more useful and were more inclined to use it in the future than VR. As expected, kinesthetic learners found the AR environment more useful than the VR environment. However, contrary to expectations, visual learners found the AR environment more useful than the VR environment. The AR interface used in this study was similar to the VR interface in every way except for the method of interaction and interface transparency. However, the interaction in the AR interface was achieved by using a fiducial marker, which may not be the ideal method of interaction for AR. This might be a factor to explain the unexpected result that visual learners found AR to be more useful than VR. True tangible interaction for AR may be achieved by using devices such as a leap motion controller that provide tangible interaction with virtual objects. From these results, the conclusion cannot be made that learner preference affects the creative design process in a given interface type.

Implications

This study has theoretical, methodological, and practical implications. The results of this study yielded some valuable information on how interface type affects the creative design process. The implications of the study provide designers and design educators with insights into the selection of different types of interfaces that affect the creative design process. Furthermore, the results of the study offer suggestions to developers of instructional and educational media and materials to create content for different types of interfaces.

Theoretical Implications

The implications of the study bridge theories from cognitive psychology, information science, and design theory to formulate explanations for the effect of interface type on the creative design process. Furthermore, the study uses AR in design, which is a relatively new area of design investigation, and the results of the study provide information about potential use of AR in design instruction. The first section of the study addressed technology traits and their effect on the creative design process.

Cognitive load theory (Sweller, 1988) has previously been applied to understanding creativity in the design process. A number of researchers have studied the relationship between performance and cognitive workload. Cognitive load theory suggests that the working memory of an individual has limited capacity and that overwhelming the working memory reduces the effectiveness of the instruction. The current study provides theoretical implications along this line. The theoretical implications can be listed as follows.

First, in the current study cognitive load and epistemic actions were correlated in the two interface types. AR interfaces offered more epistemic action compared to VR interfaces, thereby reducing the cognitive load imposed by the interface. This finding is consistent with other studies that have compared the cognitive load of VR and AR interfaces.

Second, a connection between cognitive load of a system and fixation in the design process has been suggested (Kershaw et al., 2011; Moreno et al., 2014; Youmans, 2007). The results of these studies indicate that by reducing cognitive load, fixation in the design process can be reduced as well. The current study measured fixation and established that when cognitive load is less, the fixation caused by that particular interface is reduced as well. Furthermore, the current study suggests a negative correlation between epistemic actions and fixation in the design process; therefore, when epistemic actions increase, fixation effects decrease in the design process.

Third, according to information science theory, Shannon's construct of entropy is an established method of calculating entropy or information in a process. In design theory, a number of studies have incorporated Shannon's entropy to identify fixation in the design process as well as to calculate dynamic entropy levels to suggest the level of creativity of the design process. These studies suggest that higher entropy levels mean a more creative design process and that sudden drops in entropy suggest a fixation effect in the design process.

Finally, the study establishes a theoretical connection between epistemic action and creativity in the design process, filling a critical gap in knowledge – when epistemic actions are increased, the creative design process is enhanced. Moreover, tangibility in user interfaces such as AR appear to afford more epistemic actions that reduce cognitive load, reduce fixation effects in the design process, and enhance the creative design process, as compared to WIMP-based interfaces such as VR.

The second section of the study addresses user traits and their effect on the creative design process. Specifically, the study identifies a connection between learner preference and its effect on creativity in the design process. For this purpose, learner preference was analyzed together with technology acceptance as measured by PU, PEU, and IU. The theoretical framework established the connection between PEU and creativity through intrinsic motivation. While learner preference did not significantly affect creativity, technology acceptance was higher for the AR environment, and learner preference affected PU. These theoretical implications can contribute practical insights to multiple domains on using different interface types in the design process.

Methodological Implications

AR is gaining increased attention for varied uses in different domains. In this study, AR and VR interfaces were used to validate their use in design and design education. Understanding why and how these technologies can be used in design education is crucial. The study provides empirical evidence for using AR in design and design education. This study used linkography as a protocol analysis method and to calculate entropy in the links to identify fixation and creativity in the design process. Ten participants were randomly selected for protocol analysis. Even though protocol analysis has been used to understand the effect of media interfaces such as AR and VR, few or no studies have used linkography and entropy calculations to understand the effect of these interface types on the creative design process. Moreover, this study incorporated a linkography method together with quantitative analysis to understand the impact of media interfaces on the creative design process. The methodology can be replicated and used to understand the effect of other types of interfaces on the creative design process.

Practical Implications

From a practical standpoint, the findings of this study contribute to helping designers and design educators use interfaces such as AR and VR in the design process.

The results suggest that by reducing the cognitive load the creative design process can be enhanced. In terms of teaching, this not only suggests that AR interfaces offer less cognitive load, it also confirms that decisions about using any instructional medium should be made carefully and should consider the cognitive load of the chosen instructional interface.

AR is being introduced to different fields and different education levels. One such current trend is its adoption in K-12 education. Instructional design relies on reducing cognitive load in order to improve learning efficiency. As the current study suggests, AR imposes a relatively low cognitive load on the user and therefore can be adopted efficiently in curricula.

This finding can be applied to areas other than education. For example, AR devices such as the Epson Moverio BT200 are being introduced for use in operations and maintenance in facility management. As more devices such as these become available, knowing which technologies have less cognitive load is important. Chandrasekera (2014) described a method of using AR in design critiques as an alternative to physical prototyping and observed user perception of the technology. The results of the current study provide additional justification for using AR in design education as well as in the design process.

An information technology research and advisory company, Gartner (Fenn & LeHong, 2011) suggested in their hype cycle for emerging technologies for 2014 that AR is still continuing its journey through the third phase of technology maturation. In order for technology to mature and reach its potential, research on how these technologies can be useful in different domains is necessary. The current study fills a gap by showing how AR can be useful not only in design and design education but in other domains as well.

Fixation is considered to be a negative aspect in design, in most cases hindering the creative design process. Some researchers have identified factors that cause fixation in the design process such as prior knowledge and external stimuli. Specifically, some researchers have discussed the fixation effects that are caused by standard CAD software used in design and design education (Crilly, 2015; Robertson, Walther, & Radcliffe, 2007; Veisz, Essam, Joshi, & Summers, 2012). In this study, the use of AR interfaces in the design process reduced fixation as compared to VR interfaces. While CAD software packages such as SketchUp and Solid Works have incorporated AR through plug-ins and add-ons, a true AR CAD system does not exist yet. The findings of this study are invaluable in justifying the development of such an AR CAD system to be used effectively in the creative design process.

The results of the current study show how learner preference affects user acceptance of different interface types and may affect the creative design process. Even though there was no relationship between creativity in the design process and learner preference under the AR and VR interfaces, the learners' PU, PEU, and IU were all significantly higher in the AR interface than in the VR interface. This finding is consistent with previous findings on AR and user acceptance (Chandrasekera, et al., 2012).

Limitations

The current study was designed with numerous methods of limiting errors and enhancing the validity of the research protocol in investigating the effect of tangibility in user interfaces on the design process. However, as in all research of an exploratory nature, there are some unavoidable limitations.

First, the participants were college students in a design program at one Midwestern college in the United States. Most of the students were living in the same region. The study focused on design and the design process, and the students that were recruited were design students who were in their junior and senior years of study. Even though the participants were randomly assigned to the AR or VR group, six seniors and nine juniors were in the AR group, while eight seniors and seven juniors were in the VR group. This unequal distribution might have affected the results of the study because the senior students are more experienced in the design process than the junior students. Another major limitation was the unequal gender distribution: 29 out of 30 participants were female.

The second limitation was the small number of participants recruited in the study and the small number of participants randomly selected to be analyzed through protocol analysis. One of the reasons for the small sample size was the applied experimental methodology in which a limited portion of the sample was randomly selected for protocol analysis. In addition, obtaining the required number of participants was difficult. The entire data collection took place from December, 2014 to April, 2015. Although an incentive was offered, the need to dedicate some time out of their busy and limited schedules contributed to the students' decision to refrain from participating in the study.

However, recruiting a small number of participants for protocol analysis is common because the unit of analysis is the design move rather than the participant.

Thirdly, some limitations are associated with the protocol analysis method used in this study. Despite the fact that protocol analysis is a widely used empirical research method for studying cognitive processes in design studies, the method has some accepted limitations. Protocol analysis is primarily criticized for creating an unnatural design setting within a lab environment in which participants are instructed to verbalize their thinking process while being observed. In addition, the linkography method adopted in this study has been criticized for two main reasons: the procedure is time consuming and cognitively demanding for the researchers and the subjective nature of the linking process is questionable. In this study, several methods were used to improve the objectivity of the analysis; these methods were discussed extensively in the methods section.

Fourthly, the design project that the participants worked on could have been simplified or enhanced in order to identify epistemic actions clearly. For example, by tightening the design criteria so that the participants were forced to design in a certain way they would have been compelled to use more epistemic actions to explore different possibilities.

The study incorporated desktop based VR and AR, in terms of technology these can be seen as limitations. Using HMD based display systems for both VR and AR can be a method in order to reduce this limitation.

Future Directions

This study provides a number of opportunities for further evaluation, given that the subject matter focuses on a relatively new domain in the use of AR in design education. As the technology is becoming available for use in schools, the need for such research increases. Research in this area will not only encourage design schools to adopt technology-based design education but also assist in the development of the technology.

First, the current study provides compelling evidence for the use of AR in design education to enhance the creative design process. In future research, the same methodology can be used to carry out design research with diverse populations to see if individual and cultural factors affect the use of such technology. To this aim the author of this dissertation has already focused on conducting virtual collaborative design studios among different design schools in the United States. The use of virtual critiques has been discussed in previous studies (Chandrasekera, 2015), and the current study provides empirical evidence for using some of these tools in design studios. Using the framework provided by Chandrasekera as well as the results from this study, I expect to develop an AR platform to be used in the design critique process.

Second, I hope to replicate the current study and use neuroimaging technology to understand the changes in brain function during the design process. When the pilot study of the current study was conducted, a neuroimaging device was used to analyze the changes in brain function (Chandrasekera & Yoon, 2014b). Even though a comprehensive analysis was not performed, the preliminary results showed a connection between brain function patterns and associated cognitive load. Slevitch, Chandrasekera, Yang, and Chung (2015) used the method described by Anderson et al. (2011) to analyze the cognitive load through neuroimaging data. Such a study will be helpful in validating the effect of interface type on the cognitive load imposed on the user.

Third, this study should be replicated with the use of other types of AR and VR. In this study, only one type of AR (operationalized as fiducial marker-based desktop AR) and one type of VR (operationalized as WIMP-based desktop VR) were used. The effect of different intensities of tangibility on the design process will be particularly interesting.

Fourth, I expect to describe specific characteristics that differentiate AR and VR from each other using the results and knowledge gained from this study. Currently, specific definitions that help distinguish these technologies as separate tools are lacking. This is evident in the statement that Azuma (1997) made when he mentioned that AR is a variation of VR. However, the current study clearly shows how these two technologies affect human cognitive abilities. I expect to define these technologies by focusing on the two characteristics of tangibility and interface transparency. Here, interface transparency is defined as the awareness of the interface. Understanding these factors will also help in defining the concept of "presence" in AR environments. In previous research (Chandrasekera, 2014), I suggested that AR requires a different definition (relative realism) for the concept of presence because the current definition was developed for VR. Even though initial concepts were developed by Milgram et al. (1995), further research has not been conducted.

Given the novelty of the research area, the current research provides a fertile ground to further elaborate on the results obtained. The research conducted in this study is expected to contribute not only to the field of design research but to technology-based education and AR-related research as well.

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Appendix A

VARK Questionnaire

How Do I Learn Best?

Choose the answer which best explains your preference and circle the letter(s) next to it.
Please circle more than one if a single answer does not match your perception.
Leave blank any question that does not apply.

1. You are helping someone who wants to go to your airport, the center of town or railway station. You would:
   a. go with her.
   b. tell her the directions.
   c. write down the directions.
   d. draw, or show her a map, or give her a map.
2. A website has a video showing how to make a special graph. There is a person speaking, some lists and words describing what to do and some diagrams. You would learn most from:
   a. seeing the diagrams.
   b. listening.
   c. reading the words.
   d. watching the actions.
3. You are planning a vacation for a group. You want some feedback from them about the plan. You would:
   a. describe some of the highlights they will experience.
   b. use a map to show them the places.
   c. give them a copy of the printed itinerary.
   d. phone, text or email them.
4. You are going to cook something as a special treat. You would:
   a. cook something you know without the need for instructions.
   b. ask friends for suggestions.
   c. look on the Internet or in some cookbooks for ideas from the pictures.
   d. use a good recipe.
5. A group of tourists want to learn about the parks or wildlife reserves in your area. You would:
   a. talk about, or arrange a talk for them about parks or wildlife reserves.
   b. show them maps and internet pictures.
   c. take them to a park or wildlife reserve and walk with them.
   d. give them a book or pamphlets about the parks or wildlife reserves.
6. You are about to purchase a digital camera or mobile phone. Other than price, what would most influence your decision?
   a. Trying or testing it.
   b. Reading the details or checking its features online.
   c. It is a modern design and looks good.
   d. The salesperson telling me about its features.
7. Remember a time when you learned how to do something new. Avoid choosing a physical skill, eg. riding a bike. You learned best by:
   a. watching a demonstration.
   b. listening to somebody explaining it and asking questions.
   c. diagrams, maps, and charts - visual clues.
   d. written instructions – e.g. a manual or book.

8. You have a problem with your heart. You would prefer that the doctor:

   a. gave you a something to read to explain what was wrong.
   b. used a plastic model to show what was wrong.
   c. described what was wrong.
   d. showed you a diagram of what was wrong.

9. You want to learn a new program, skill or game on a computer. You would:

   a. read the written instructions that came with the program.
   b. talk with people who know about the program.
   c. use the controls or keyboard.
   d. follow the diagrams in the book that came with it.

10. I like websites that have:

    a. things I can click on, shift or try.
    b. interesting design and visual features.
    c. interesting written descriptions, lists and explanations.
    d. audio channels where I can hear music, radio programs or interviews.

11. Other than price, what would most influence your decision to buy a new non-fiction book?

    a. The way it looks is appealing.
    b. Quickly reading parts of it.
    c. A friend talks about it and recommends it.
    d. It has real-life stories, experiences and examples.

12. You are using a book, CD or website to learn how to take photos with your new digital camera. You would like to have:

    a. a chance to ask questions and talk about the camera and its features.
    b. clear written instructions with lists and bullet points about what to do.
    c. diagrams showing the camera and what each part does.
    d. many examples of good and poor photos and how to improve them.

13. Do you prefer a teacher or a presenter who uses:

    a. demonstrations, models or practical sessions.
    b. question and answer, talk, group discussion, or guest speakers.
    c. handouts, books, or readings.
    d. diagrams, charts or graphs.

14. You have finished a competition or test and would like some feedback. You would like to have feedback:

    a. using examples from what you have done.
    b. using a written description of your results.
    c. from somebody who talks it through with you.
    d. using graphs showing what you had achieved.

15. You are going to choose food at a restaurant or cafe. You would:

    a. choose something that you have had there before.
    b. listen to the waiter or ask friends to recommend choices.
    c. choose from the descriptions in the menu.
    d. look at what others are eating or look at pictures of each dish.

16. You have to make an important speech at a conference or special occasion. You would:

    a. make diagrams or get graphs to help explain things.
    b. write a few key words and practice saying your speech over and over.
    c. write out your speech and learn from reading it over several times.
    d. gather many examples and stories to make the talk real and practical.

Appendix B

NASA TLX

Name	Task	Date

Mental Demand How mentally demanding was the task?

Very Low — Very High

Physical Demand How physically demanding was the task?

Very Low — Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very Low — Very High

Performance How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix C

Technology Acceptance Model Questionnaire

1. It was easy to understand the instructions

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

2. It took a long time to learn to use the system

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

3. This system is difficult to use

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

4. I felt in control over the system

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

5. My interaction with the system is clear and understandable

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

6. Interacting with the system does not require a lot of my mental effort

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

7. I find the system to be easy to us

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

8. This system is fun to use

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

9. I find it easy to get the system to do what I want it to do

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

10. I would like to use this type of system to receive instructions in my profession.

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

11. I would like to use this system in other contexts than my profession.

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

12. I feel confident that the system is giving me correct instructions.

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

13. I would prefer to receive instructions from a person (teacher/tutor)

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

14. The system does not have any apparent shortcomings

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

15. I experienced nausea, dizziness or discomfort while using the system

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

16. I would have difficulty explaining why using the system may or may not be beneficial.

Strongly Disagree			Neither			Strongly Agree
1	2	3	4	5	6	7

Appendix D

Oklahoma State University Institutional Review Board

Date:	Thursday, April 03, 2014
IRB Application No	HE1411
Proposal Title:	Using Augmented Reality and Virtual Reality in Design Education
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved   Protocol Expires: 4/2/2015

Principal Investigator(s):

Tilanka Chandrasekera
429D HS
Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

X The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval. Protocol modifications requiring approval may include changes to the title, PI advisor, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms
2. Submit a request for continuation if the study extends beyond the approval period. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of the research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Dawnett Watkins 219 Cordell North (phone: 405-744-5700, dawnett.watkins@okstate.edu).

Sincerely,

Shelia M. Kennison

Shelia Kennison, Chair
Institutional Review Board

Appendix E

Recruiting Letter

Dear students,

We are currently seeking volunteers to take part in a design research project which will take place during November 2014-January 2015. At the moment we require thirty volunteers and any additional volunteers will be kept on file for future studies. You will be compensated with $25 for your participation in this study

In this study you will complete three work sessions. The first session will introduce you to the AR/VR interface including various techniques for moving within and interacting with different icons, after which they will be taught to create basic design interventions and to blend different skills in the interface. You will also answer a basic demographic survey and a learner typology questionnaire. In the second session, you will work on an interior design of a small office space. At the end of the session, you should provide an idea of the 3-dimensional form for the small office space and a schematic layout. As and when you are doing the task you will think-aloud about the conceptual process of design. In the third session, you will be asked to express your experience in assessing the capabilities and limitations of the AR and VR tools through a survey.

The design project itself will be a short span project (lasting about one hour) in which we will test digital technology and its impact on design. We will be trying to examine the impact of AR and VR tools in design creativity. Your design process and products will be documented in video by our research assistant and we will analyze it later on. We will also analyze your brain wave patterns using a small brain cap which is noninvasive.

From a teaching perspective, as instructors, we will be able to better understand your interaction with the digital media and how technology helps or disrupts the design process. From a learning perspective, as students, you will have the opportunity to interact with some of the state-of-the-art technology. You don't have to be technically savvy to do this project but some basic software skills will be helpful.

This participation is purely on voluntary basis. If you are interested to learn further or explore this option please contact Tilanka Chandrasekera

Tilanka Chandrasekera

429D, Human Sciences

405-744-9524

tilanka@okstate.edu

Appendix F

Informed Consent Form for Social Science Research

Title of Project: Using Augmented Reality and Virtual Reality in Design education

Principal Investigator: Tilanka Chandrasekera

429D, Human Sciences

405-744-9524

tilanka@okstate.edu

Student Investigator: Noriel Grey

1. Purpose of the Study: The purpose of this research is to explore the efficacy of using digital tools in the design process. Specifically the study will examine how Augmented Reality (AR) and Virtual Reality (VR) tools are used by design students in the design process

2. Procedures to be followed: The study will consist of three work sessions, which are elaborated below.

a. Session-1: Training

The first session will introduce you to the AR/VR interface including various techniques for moving within and interacting with different icons, after which they will be taught to create basic design interventions and to blend different skills in the interface. You will also answer a basic demographic survey and a learner typology questionnaire

b. Session-2: Design Task

In the second session, you will work on an interior design of a small office space. At the end of the session, you should provide an idea of the 3-dimensional form for the small office space and a schematic layout. As and when you are doing the task you will think-aloud about the conceptual process of design. While in the design task, you will be fitted with a headset that measures brainwave activity while you are completing your assigned task.

c. Session-3: Conclusion

In the third session, you will be asked to express your experience in assessing the capabilities and limitations of the AR and VR tools through a survey.

3. Discomforts and Risks: There are no risks in participating in this research beyond those experienced in everyday life.

4. Duration/Time: approximated 1 hour.

5. Benefits and compensation: You will be compensated $25.00 for participating in this study. Additionally, you will benefit by receiving free training on state of the art design tools similar to ones used in professional firms. You also gain valuable practical experience as part of the training during your participation.

6. Statement of Confidentiality: Your interactions while using the AR/VR tools will be electronically recorded directly from the computer screen. This recording will not include any personal information and you are requested not to enter any personally identifiable information on the computer during the sessions. Your actions will be video recorded and your voice will be audio recorded while designing. No personal information will be collected and only the researchers will have access to the information collected. Your participation in this research is therefore confidential. The data will be stored and secured at 429D, Human Sciences in a locked and password-protected file. The Oklahoma State University's Institutional Review Board may review records related to this research study.

7. Right to Ask Questions: Please contact Tilanka Chandrasekera 405-744-9524 with questions about this research. If you have any questions, concerns, problems about your rights as a research participant, please contact the Oklahoma State University's Review Board. Attn: Dr. Hugh Crethar, IRB Chair, 219 Cordell North, 405-744-3377, or irb@okstate.edu. Questions about research procedures can be answered by the research team.

8. Voluntary Participation: Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty. You must be 18 years of age or older to consent to take part in this research study. You will be given a copy of this consent form for your records.

Appendix G

Demographic Survey

We greatly appreciate your taking the time to complete this simple questionnaire. All answers are confidential and you will not be able to be identified from the information you provide.

Please mark the appropriate answer by either underlining or circling the correct answer. Some questions may ask you to mark all answers that apply.

Section - One

1. What is your gender?

A. Male

B. Female

2. What is your race and ethnicity background?

A. White

B. Black or African American

C. American Indian and Alaska Native

D. Indian or South Asian

E. Asian

F. Native Hawaiian and other Pacific Islanders

G. Hispanic, Latino or Spanish origin

H. Other (Please specify:________________)

3. How old are you?

A. 18-25

B. 25-30

C. 30-35

D. Above 35

4. Where is your home town?

5. What's your academic level?

A. Freshman

B. Sophomore

C. Junior

D. Senior

For question 6-7: Note- the more frequent the activity the higher the numerical rating. Please circle the numerical that you feel most correctly correlates with the value that you assign.

6. I play/have played, video/computer games…

Not at all — Moderately — Frequently

1	2	3	4	5	6	7

7. I use computers …

Not very much — Moderately — Frequently

1	2	3	4	5	6	7

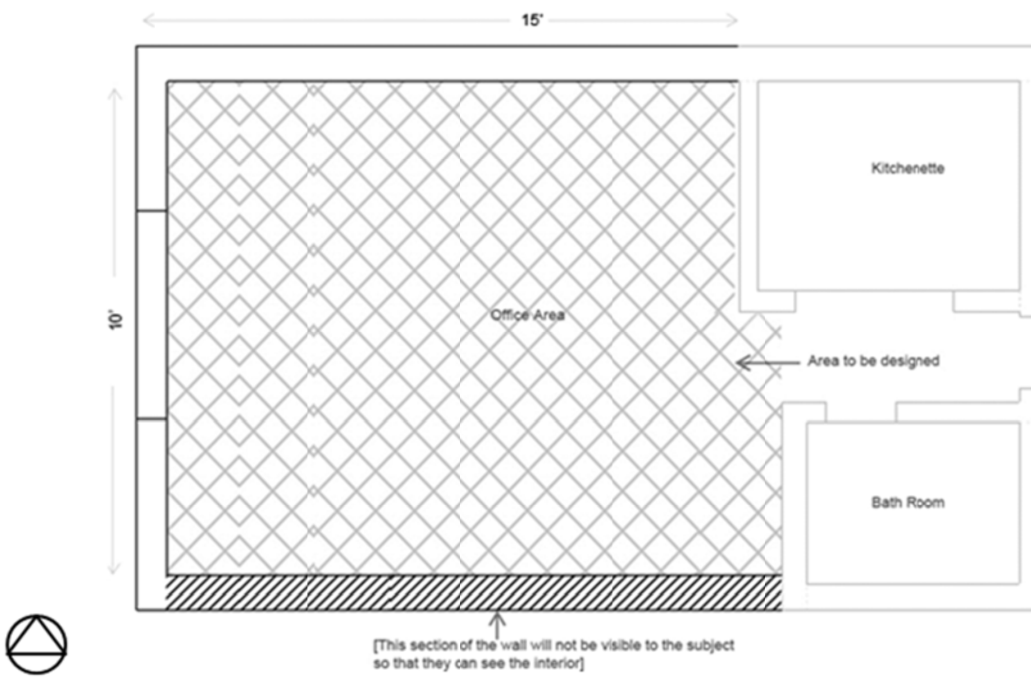
Appendix H

AR VR Operational Training Manual

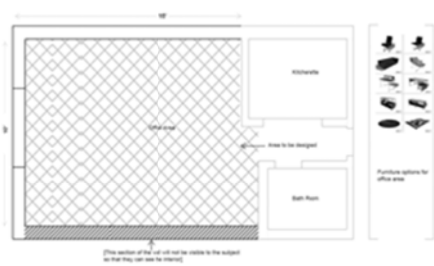
Design Brief

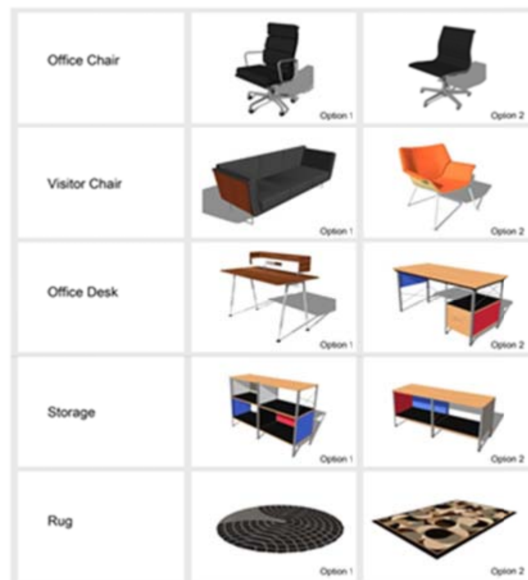
[Design Bio]

Mike Stewart is a up and coming accountant based in Overland Park, Kansas. He just started his business and is in the process of setting up his new office. Currently he is the only person who is working in the office, and he doesn't anticipate hiring anyone soon. Mike has already selected some furniture that he likes, but has not been able to make his mind. He needs your help to select the appropriate furniture and place them in the office, giving consideration to aesthetics, color, functionality, orientation, fenestrations (doors and windows) and circulation.



Here is the Layout of the office



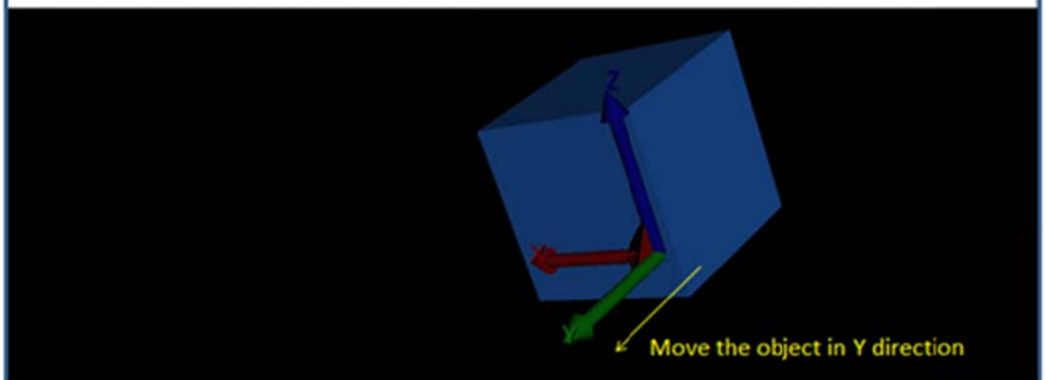


Herman Miller furniture provided
Use 5 furniture components to design the interior of the office

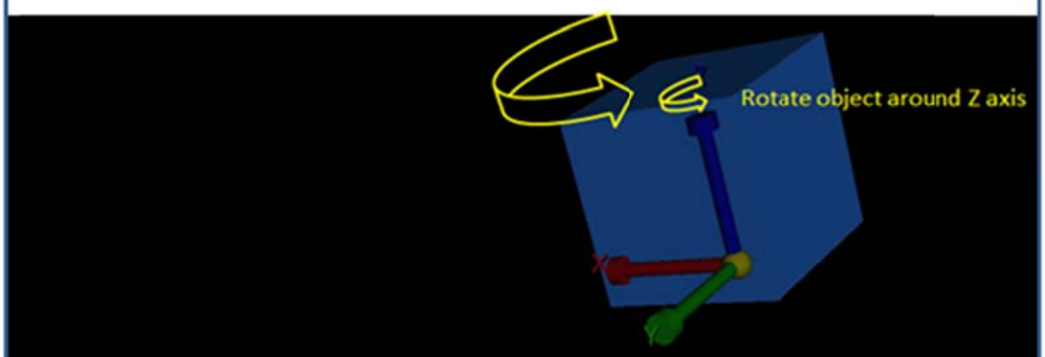
Training Session

In the VR system you can

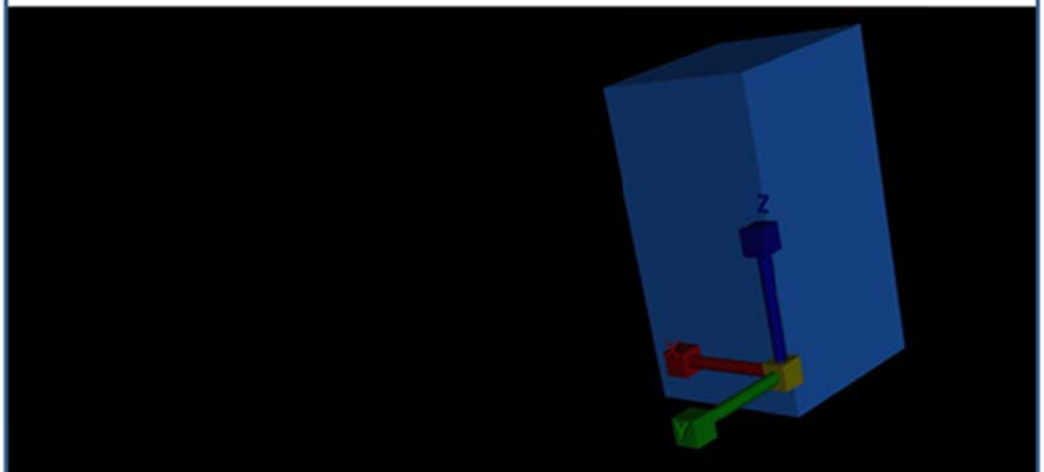
- move the piece of furniture in X, Y, and Z directions
- change the rotation angle
- And rescale (it is not recommended that you change the scale)



Clicking on the object will activate moving, rotating or resizing tool. Using the mouse cursor



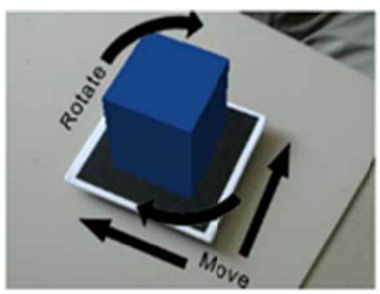
Right click to switch to rotation . Using the mouse curser
Drag in the direction you want to rotate the object



Even though it is not recommended you can right click to switch to resize . Using the mouse curser drag in the direction you want to resize the object.

In the AR system you can

- move the piece of furniture in X, Y, and Z directions
- change the rotation angle
- ...by manipulating the marker that is provided for the piece of furniture



Appendix I

Workload Tally Sheet and Weighted Rating Worksheet

Subject ID: ________________ **Date:** ______________

SOURCES-OF-WORKLOAD TALLY SHEET		
Scale Title	*Tally*	*Weight*
MENTAL DEMAND		
PHYSICAL DEMAND		
TEMPORAL DEMAND		
PERFORMANCE		
EFFORT		
FRUSTRATION		

Total count = ____________

(NOTE - The total count is included as a check. If the total count is not equal to 15, then something has been miscounted. Also, no weight can have a value greater than 5.)

Subject ID: ____________ Task ID: ____________

WEIGHTED RATING WORKSHEET			
Scale Title	*Weight*	*Raw Rating*	*Adjusted Rating* (Weight X Raw)
MENTAL DEMAND			
PHYSICAL DEMAND			
TEMPORAL DEMAND			
PERFORMANCE			
EFFORT			
FRUSTRATION			

Sum of "Adjusted Rating" Column = ______

WEIGHTED RATING =
[i.e., (Sum of Adjusted Ratings)/15]

VITA

Tilanka Chandrasekera is a licensed Architect who has practiced Architecture in Sri Lanka. He has a Bachelors and Masters degrees in Architecture (RIBA Accredited) from the University of Moratuwa, Sri Lanka. He has worked as an individual consultant as well as in several different Architectural firms in Sri Lanka. As an Architect, Tilanka has worked in projects ranging from Highrise designs, Wild life parks, Zoo's, Hotels and personalized housing.

He has taught in the Department of Architectural studies at the University of Missouri-Columbia and has also been a visiting lecturer and a design tutor at the University of Moratuwa, Sri Lanka. He has been working as an Assistant Professor at the Department of Design, Housing and Merchandising at Oklahoma State University since August 2013.

With regard to research, Tilanka is interested in the nexus of Digital Media and Design education. Some of his current research interests include Application of Tangible User Interfaces in Design Education, Application of digital technology for geriatric design practices (Gerontechnology), Design Computing and Cognition, Navigation and wayfinding research in interior environments.

Tilanka has won numerous awards for his teaching and research including The Council for Interior Design Accreditation (CIDA) Innovative Education Award- 2013 and Architecture Research Centers Consortium (ARCC) King Student Medal for Excellence in Architectural & Environmental Design Research-2012.