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Playing to Win: Applying Cognitive Theory and Gamification to Augmented Reality for Enhanced Mathematical Outcomes in Underrepresented Student Populations TeAirra Monique Brown

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Industrial and Systems Engineering

Joseph L. Gabbard, **Chair**

Jeremy V. Ernst Anita Franklin Nathan Ka Ching Lau May 21, 2018 Blacksburg, VA Keywords: Augmented Reality, Cognitive Theory of Multimedia Learning, Gamified Learning Application, Cognitive Load, Mathematics © by TeAirra M. Brown Playing to Win: Applying Cognitive Theory and Gamification to Augmented Reality for Enhanced Mathematical Outcomes in Underrepresented Student Populations TeAirra Brown ABSTRACT National dialogue and scholarly research illustrate the need for engaging science, math, technology, and engineering (STEM) innovations in K-12 environments, most importantly in low- income communities

(President's Council of Advisors on Science and Technology, 2012). According **to** Educating **the**

Engineer of 2020, "current curricular material does not portray STEM in ways that seem likely to excite the interest of students from a variety of ethnic and cultural backgrounds" (Phase, 2005). The National Educational Technology Plan of 2010 believes that one of the most powerful ways to transform and improve K-12 STEM education it to instill a culture of innovation by leveraging cutting edge technology (Polly et al., 2010). Augmented reality (AR) is an emerging and promising educational intervention that has the potential to engage students and transform their learning of STEM concepts. AR blends the real and virtual worlds by overlaying computer-generated content such as images, animations, and 3D models directly onto the student's view of the real world. Visual representations of STEM concepts using AR produce new educational learning opportunities, for example, allowing students to visualize abstract concepts and make them concrete (Radu, 2014). Although evidence suggests that learning can be enhanced by implementing AR in the classroom,

it is important to take into account how **students are**

processing AR content. Therefore,

this research aims **to** examine **the** unique **benefits and challenges** of utilizing **augmented reality**

(AR) as a supplemental learning technique to reinforce mathematical concepts while concurrently responding to students' cognitive demands. To examine and understand how cognitive demands affect students' information processing and creation of new knowledge, Mayer's

Cognitive Theory of Multimedia Learning (CTML) is leveraged **as a** theoretical **framework to** ground **the** AR application **and** supporting research. Also, **to** enhance students' **engagement,**

gamification was used to incorporate game elements (e.g. rewards and leaderboards) into the AR applications. This research applies gamification and CTML principles to tablet-based gamified learning AR (GLAR) applications as a supplemental tool to address three research objectives: (1) understanding the role of prior knowledge on cognitive performance, (2) examining if adherence to CTML principles applies to GLAR, and, (3) investigating the impact of cognitive style on cognitive performance. Each objective investigates how the inclusion of CTML in gamifying an AR experience influences students' perception of cognitive effects and how GLAR affects or enhances their ability to create new knowledge. Significant results from objective one suggest, (1) there were no differences between novice and experienced students' cognitive load, and, (2) novice students' content-based learning gains can be improved through interaction with GLAR. Objective two found that high adherence to CTML's principles was effective at (1) lowering students' cognitive load, and, (2) improving Celestial Blast performance. The key findings of objective three are (1) cognitive load of FD students is significantly lower in the VonChigh condition relative to the other conditions when voice and coherence were manipulated, (2) FD students' cognitive load remained constant across the four experimental conditions when voice and coherence were manipulated, and, (3) both FID and FD students had content-based learning gains after engagement with Build-A-World. The results of this research adds to the existing knowledge base for researchers, designers and practitioners to consider when creating gamified AR applications. Specifically, this research provides contributions to the field that include empirical evidence to suggest to what degree CTML is effective as an AR-based supplemental pedagogical tool. And moreover, offers empirical data on the relationship between students' perceived benefits of GLAR and it is impact on students' cognitive load. This research further offers recommendations as well as design considerations regarding the applicability of CTML when developing GLAR applications. GENERAL AUDIENCE

ABSTRACT The purpose of this research **is to examine the** unique benefits **and** challenges **of**

using augmented reality (AR) to reinforce underrepresented students' math concepts while observing how their process information. Gamification and

Mayer's Cognitive Theory of Multimedia Learning (CTML) principles are applied **to**

create tablet-based gamified learning AR (GLAR) applications to address three research objectives: (1) understanding the role of prior knowledge on cognitive performance, (2) examining if adherence to CTML principles applies to GLAR, and, (3) investigating the impact of cognitive style on cognitive performance. Each objective investigates how the inclusion of CTML in gamifying an AR experience influences students' perception of cognitive effects and how GLAR affects or enhances their ability to create new knowledge. This research offers recommendations as well as design considerations regarding the applicability of CTML when developing GLAR applications. DEDICATION I dedicate this dissertation

to my Lord and Savior Jesus Christ for ordering my steps **and**

never leaving my side.

This dissertation is also **dedicated to my family,** especially **to** my grandmother **the**

late Helen Brown, to my mother Wanda Boone and to my sister RaNashia Boone.

I would like to thank my family for their unwavering **love and support throughout**

this journey and for being an amazing support system. Thank you for keeping me grounded, encouraging me to walk in faith every step of the way and speaking life over me. To my grandmother, I don't know who or where

I would be without your love, faith and fortitude. Thank you for teaching me to be determined when facing obstacles, keeping me covered in prayer and interceding on my behalf. To my mother, I am forever grateful to you for encouraging me to walk in my destiny, pushing me to greatness, standing in faith with me and for seeing something in me even when I could not see it in myself. Thank you for your resilience, for being my role model, voice of reason, motivator, and for everything you sacrificed to ensure that I was able to follow my dreams. Lastly to my sister, you made me more determined to seek God, follow my dreams and walk in my purpose because I knew you were watching.

Thank you for your strength, compassion, **and for believing in** and motivating **me** when **I**

had self-doubts and wanted to give up. RaNashia, I want you to remember to always blaze your own trail, believe in the beauty of your dreams and walk boldly into God's purpose for your life.

The Lord is my strength and my shield; my heart trusts in him, and I am helped. My heart leaps for joy and I will give thanks to him in song. Psalm 28:7

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 of Problem National dialogue and scholarly research illustrate the need for science, math, technology, and engineering (STEM) innovations in K-12 environments, and more importantly, its need in low-income communities

(President's Council of Advisors on Science and Technology, 2012). Today, success **of**

low-income children in public school is difficult to achieve. A 2008 report submitted by the House Bill 2722 Advisory Committee states, "the education system was never designed to educate the diversity of students currently in public schools." As a result, the disparity between various socioeconomic groups of students is known as the achievement gap. This issue encompasses many problems such as the lower achievement level that low-income students demonstrate in subjects such as reading and mathematics. One of the initiatives implemented to close the achievement gap is the

No Child Left Behind (NCLB) **Act** of 2002. **The** goal **of NCLB was to** monitor **students'**

progress toward achieving grade level expectations through annual assessments, and to hold schools accountable for the results (Thompson, 2007; NCES, 2011). Despite remarkable efforts and safeguards such as NCLB, the achievement gap remains present due to key differences between the educational communities of underserved and high- income students (NCLB Act, 2001). A pivotal difference between these communities is the engagement and cognitive development (or lack thereof) for students to achieve expected goals. Therefore, researchers must continue to develop interventions to close the achievement gap to address these differences. The National Educational Technology Plan of 2010 believes that one of the most powerful ways to transform and improve K-12 STEM education it to instill a culture of innovation through technology use. Research suggests, moving forward, that we need to leverage cutting-edge technology to engage students and ensure their development of STEM capabilities reach levels beyond what was considered acceptable in the past (Rosenberg, 2005). Utilizing technology is an educational intervention that offers great promise at effectively promoting student achievement and closing the gap. One of these emerging and promising learning technologies is augmented reality (AR), which according to the 2010 Horizon Report, has the potential to impact learning and transform students' learning experiences (Johnson, Larry, Smith, & Stone, 2010). AR blends the real and virtual worlds by overlaying computer-generated content such as images, animations, and 3D models directly onto the student's view of the real world. AR offers great promise by leveraging the unique blending of virtual objects and the real world to produce new educational opportunities by, for example, allowing students to visualize abstract concepts and make them concrete (Radu, 2014). AR could increase engagement and positively impact the cognitive processes of students if it is well-designed (Dunleavy, Dede, Mitchell, 2009). The visual representations of concepts using AR produce learning gains that are difficult to achieve in other educational technologies (Wu et al., 2013); however, there are some limitations and drawbacks that should be addressed if we want to leverage AR in the K-12 environment. Some of the potential challenge researchers face are creating authentic AR learning environments, engaging students beyond the novelty effect and reducing students' cognitive load. Cognitive load is the total amount of mental effort and /or information that the working memory can hold at a given time (Sweller, 1988;

2010). According to Haslma and Hamilton (2010), understanding how students learn and how their cognitive load can be affected is essential when designing learning technology. Currently, AR learning applications are not

driven by pedagogy but more by the strengths and weaknesses of the

AR authoring software and tools (Lee et al., 2 2004). This limitation hinders the design of AR and could lead to applications having too much information, irrelevant graphics and virtual objects, or burdensome user interaction (Medula, 2012). AR should improve students' conceptual understanding of learning content and keep them engaged without overwhelming them cognitively. Thus, in order to facilitate learning with AR, researchers need to limit the demands on students' working memory to manageable pieces otherwise students' learning will be limited by overloading the cognitive abilities of students (Sweller, 1998; Ayres, 2006). Another drawback: AR learning applications are being designed without considering the cognitive differences among students and how these differences affect students' information processing (O'Shae et al, 2001). In order for students to reach their maximum learning potential, the design of AR should support individual factors so the

use of technology is not detrimental to learning (Radu, 2014). The design of

AR could impact the cognitive and psychology development of students; therefore, cognitive differences should be taken into account. However, research is still needed to investigate how cognitive differences could influence how students use and understand the educational content when using AR. Although Radu (2014) began to examine how students'

psychological and physiology development influence their ability to use AR applications,

further analyses are needed to ensure AR meets the cognitive needs of the students to improve learning outcomes. 1.2 Motivation Educators and researchers are constantly seeking educational technology to

meet the needs of all students. The utilization of AR for educational purposes

can impact the learning environment for students by increasing their engagement and immersing them

in an augmented environment where they can take an active role in learning process

by manipulating virtual objects (Billinghurst, 3 Kato, & Poupyrev, 2001). For example, Construct3D allowed students to inspect three dimensional geometric structures by virtually rotating the structures using their hand. As the student moved the structure, they were able to analyze the properties of the structures by viewing multiple perspectives and manipulating scalability to zoom in and out (Kaufmann, Schmalstieg & Wagner, 2000). With the evolution and advancement of AR, it is important for researchers to investigate how to effectively design the technology for educational enhancement. Understanding how to optimally design AR learning applications that lower the cognitive demands on students and facilitate learning is a high priority (Bruning et al., 2004). Although previous studies show that AR can potentially improve learning by increasing the understanding of spatial relationships, providing authentic contextualized learning experiences, improving long-term recall and cultivating positive collaborations, both the educational and technological communities remain unclear on the cognitive demands AR has on the working memory (Shelton & Hedley, 2003). There is limited research and evidence to help designers identify students' cognitive processing abilities when using multimedia instruction, especially in the K-12 learning environment. According to Calhoun (2012),

prior research involving cognitive processing relied heavily on the development **of**

multimedia instruction without emphasis on the effects of the multimedia design techniques or how to measure cognitive processing. Therefore, this research will consider the role of

Mayer's Cognitive Theory of Multimedia Learning (CTML), an

educational psychology theory, to account for cognitive processes of students within the K-12 environment. Understanding the role of CTML and how the design of AR affects cognitive load will help build the current body of knowledge. It will enhance the literature by documenting the specific benefits and challenges of grounding AR in CTML. This research will provide strategies 4 to maximize students' cognitive processing as well as strengthen researchers and designers' capacity to better design and utilize AR in the classroom to help all students exceed expected learning goals. 1.3 Theoretical Framework CTML will guide this research to examine the effect of cognitive load and ground the AR applications in learning theory. CTML states that the human brain

can only process a finite **amount of information in a given** sensory **channel**

and

processing of sensory information is processed separately according to its modality

(Mayer & Moreno, 2003). Thus, the limited working memory of the brain may be the most critical factor that needs to be considered in how students are processing information (Mayer, 2005). Sometimes the

working memory of students **is overloaded due to inappropriate** methods **of**

presenting learning content (De Jong, 2010). Mayer bases CTML based on three assumptions: 1) working memory includes dual channels of modality which allow for visual and auditory processing; 2) the channels have

a limited capacity for processing information which **can be overloaded;**

and 3) learning is an active process that integrates new information with prior knowledge then stores to long-term memory (Mayer & Moreno, 2003).

According to Mayer, knowledge construction from auditory and visual cues happens when the student is engaged in five cognitive processes (figure 1): 1. selecting relevant words for processing in auditory working memory, 2. selecting relevant images for processing in visual working memory, 3. organizing selected words into a verbal model, 4. organizing selected images into a pictorial model, and, 5. integrating the words and images with each other and with prior knowledge. Figure 1: The

Cognitive Theory of Multimedia Learning (Mayer, 1997) CTML assumes that

"information must be actively selected, organized and integrated with existing prior knowledge in order for learning to occur." Students must be able

to select and organize information in working memory then

integrate these representations with prior knowledge. The theory is centered on the idea that students build meaningful connections with content when they process information using two modalities. These processes allow students to build a mental representation from the content being presented, then transfer that representation to knowledge efficiently. The theory assumes that the representations need to be actively organized and

integrated with existing prior knowledge in order for learning to occur.

When a student can fully engage in all five cognitive processes (figure 1) then they are actively learning without experiencing cognitive overload (Sorden, 2012). Essentially, CTML encompasses the ideas from other researchers and is influenced by other theories such as

Cognitive Load Theory and Dual-Coding Theory. Mayer used these theories

to help with the creation of several principles he proposed for designing learning technology that addresses his three assumptions and reduce cognitive load. Some of the principles he proposed to guide the design of multimedia learning are: coherence, personalization, segmenting, contiguity, and signalizing. Imploring these principles to shape the design of technology should reduce extraneous processing, promote the transformation of free cognitive resources and maximize the use of cognitive processing needed for processing information (Rusanganwa, 2013; Sung & Mayer, 2013; Ayers, 2013; Aldalalah, 2012; Ibrahim, Antonenko, Greenwood, & Wheeler, 2012; Florax & Ploetzner, 2010). Thus, it follows that AR that is designed inappropriately may hinder students' abilities to engage the five cognitive processes and subsequently, hinder their understanding of concepts. Research shows that AR learning applications are effective at helping students encode and retain information into long term memory to be retrieved later for real-world application or to solve a new problem (Majoros & Neumann, 2001; Valimont, 2002). However, CTML doesn't explain how utilizing multi-modal sensory AR applications aid in information processing and integration in the working memory by retrieving prior knowledge. Therefore, it is hypothesized that the inclusion of CTML and applying

Mayer's principles when designing and creating AR will maximize the limited capacity of the working memory and account for the information being presented through dual modality (Clark, Nguyen & Sweller, 2011; Mayer, 2010; Mayer, Fennell, Farmer, & Campbell, 2004; Moreno & Mayer, 2002). 1.4

Research Purpose, Objectives **and** Questions **The** main **purpose of this research is to examine the** unique benefits **and** challenges **of**

utilizing augmented reality (AR) as a supplemental learning technique to reinforce mathematical concepts while responding to students' cognitive resources. Specifically, this research will evaluate the effectiveness of CTML as an AR-based learning pedagogy and investigate how the inclusion of AR in the classroom could impact the cognitive load of fifth grade students. Since the opportunity to use AR in fifth grade classrooms to engage students and respond to their cognitive demands has not been fully realized, an aim of this work is to better understand how to provide students with authentic technology-based learning experiences that keep them engaged while not overloading them cognitively. To enhance students' engagement, gamification was used to incorporate game elements (e.g. rewards and leaderboards) into AR applications created specifically to support this research. Gamification applies game-like elements and principles in a non-gaming environment with the desired outcome of increasing engagement, motivation and learning. Gamification is not solely about developing a game, but instead about applying game attributes to stimulate students, leaving them excited about learning (Arnold, 2014). Successful gamified applications assert and intertwine game elements while providing feedback and encouraging the student to work toward the next level (Morris et al, 2013; Wood & Reiners, 2012). Based on previous empirical studies, it is hypothesized that the application of gamification in this study will increase students' engagement and cognitive processing (Busteed, 2013; Hamari, Koivisto & Sarsa, 2014). This research will apply gamification and CTML principles to tablet-based gamified learning AR (GLAR) applications as a supplemental tool to address three research objectives as summarized in table 1. The advantages of using tablets include the fact that tablets are less obtrusive and cost-effective and are more representative of technology currently found in the classrooms (as opposed to expensive head-worn AR technology). Despite the lower cost point, tablet-based AR can still provide students benefits such a sense of immersion and multiple viewing perspectives. Table 1: Research Objective Summary Objective 1. Understanding the role of prior knowledge on cognitive performance 2. Examine if adherence to CTML principles apply to GLAR 3. Investigate the impact of cognitive style on cognitive performance Research Questions Does prior exposure to learning content have an actual and perceived effect on GLAR performance? Does prior exposure to learning content effect cognitive load when using GLAR application "Celestial Blast"? Will engagement with GLAR improve content- based

learning gains for **students with and without prior exposure to**

learning content? Does GLAR interfaces' level of adherence to CTML principles affect students' cognitive load? Does high adherence to the principles of CTML result in higher students' GLAR performance? Is the cognitive load of field- independent and field-dependent students impacted when voice and coherence principles of

CTML are manipulated in GLAR application “Build-A-World”? Does students’ cognitive style impact GLAR performance when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? Are there content-based learning gains for field-independent and field-dependent students when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? Independent Variables Prior Knowledge (2 levels) Display Adherence Interfaces (3 levels) Cognitive Style (2 levels) Voice Principle (2 levels) Coherence Principle (2 levels) Dependent Variables Pre- and Post- Assessment Scores High Game Score Game Attempts NASA TLX Focus group interviews High Score Game Attempts NASA TLX QUIS Survey Pre- and Post- Assessment Scores High Score Correct Game Question Percentage NASA TLX QUIS Survey Experimental Design n = 35 Mixed method Between-subjects design n = 22 Single factor repeated measures Within-subjects design Display Adherence Interfaces – 3x3 Latin square n = 26 2 x 2 x 2 mixed factor

design with one between-subject factor and two **within-subject**

factors Cognitive Style (2) x Voice Principle (2) x Coherence Principle (2) x – randomize Objective 1: Understanding the role of prior knowledge on cognitive performance ? Research Question 1: Does prior exposure to learning content have an actual and perceived effect on GLAR performance? Hypothesis (H1): There are significant actual difference in GLAR performance between students with and without exposure to learning content. ? Research Question 2: Does prior exposure to learning content effect cognitive load when using GLAR application “Celestial Blast”? Hypothesis (H2): There are

significant difference in cognitive load between students **with and without**

exposure to learning content when using GLAR application “Celestial Blast”. ? Research Question 3: Will engagement with GLAR improve content-based

learning gains for **students with and without prior exposure to**

learning content? Hypothesis (H3): Engagement with GLAR improves content-based learning gains for both students with and without prior exposure. Hypothesis (H4): There is no significant difference between content-based

learning gains for **students with and without prior exposure.** Objective **2:**

Examine if the adherence to CTML principles apply to GLAR ? Research Question 4: Does GLAR interfaces’ level of adherence to CTML principles affect students’ cognitive load? Hypothesis (H5): Students’ cognitive load is significantly lower when there is high adherence to the principles of CTML. ? Research Question 5: Does high adherence to the principles of CTML result in higher students’ GLAR performance? Hypothesis (H6): High adherence to the principles of CTML does result in higher students’ GLAR performance. Objective 3: Investigate the impact of cognitive style on cognitive performance ? Research Question 6: Is the cognitive load of field-independent and field-dependent students impacted when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? Hypothesis (H7): The cognitive load of field-dependent students is significantly lower in the VonChigh condition relative to the other conditions when voice and coherence principles of CTML are manipulated in “Build-A-World”. Hypothesis (H8): Field-independent students’ cognitive load remains constant across the four experimental design conditions when the voice and coherence principles of CTML are manipulated. ? Research Question 7: Does students’ cognitive style impact GLAR performance when voice and coherence principles of CTML are manipulated in GLAR application “Build-A- World”? Hypothesis (H9):

Field-dependent students perform significantly higher **relative to field- independent students**

when the experimental condition of the coherence principle is high in the GLAR application “Build-A-World”. Hypothesis (H10): Field-independent students’ GLAR performance improves when the experimental condition of the voice principle is off in the GLAR application “Build-A- World”. ? Research Question 8: Are there content-based learning gains for field-independent and field-dependent students when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? Hypothesis (H11): There are content-based learning gains for both field-independent and field-dependent students after engagement with “Build-A-World”. Hypothesis (H12): The content-based learning gains is significantly higher for field- dependent students relative to field-independent students after engagement with “Build-A- World”. 1.5 Methodology Overview This research is composed of three studies that used controlled human-subjects experiments to address questions related to each objective. As described in detail in Chapters 3, 4 and 5, these objectives were examined through multiple data collection instruments and techniques. In each study, the target population was

fifth grade students at **Title I schools in** the state of **Virginia and**

the settings were controlled environments on the campus of

Virginia Polytechnic Institute and State University and **the** Boys **and** Girls Club **of**

Southeast Virginia. The design of each study supports the overarching goal of examining to what extent CTML is an effective theoretical framework for designing GLAR applications and investigating how principles of CTML may reduce students’ cognitive load. Each objective investigates how the inclusion of CTML in gamifying an AR experience influences students’ perception of cognitive effects and how it affects or enhances their ability to create new knowledge. 1.5.1 Objective 1 - Understanding the role of prior knowledge on cognitive performance The cognitive demands for interpreting and integrating information may be overwhelming for some students due to the lack of prior knowledge related to a specific learning topic (Jones, Gardner, Taylor, Wiebe & Forester, 2010). Experienced students need

less working memory to organize and integrate new information

than novice students due to more robust schemas stored in their long-term memories and prior exposure to content. Study one utilized a mixed method, between-subjects experimental design involving 35 students to examine how experienced and 12 novice students perceive their cognitive load after interacting with a GLAR application. The quantitative research methods evaluated the influences GLAR had on students with regard to cognitive load and knowledge creation. Complementary qualitative data adds an additional layer of information on students' perceived cognitive effects after being exposed to the GLAR application. The qualitative data was gathered through open-ended focus groups, whereas the quantitative data was collected through pre- and post- assessments and cognitive load surveys. The results of study one aim to give direct insights into students' perspectives in regard to possible benefits and challenges of using GLAR, their perceived cognitive load and how prior knowledge may affect cognitive load and knowledge creation. 1.5.2 Objective 2 – Examine if the adherence to CTML principles apply to GLAR Research in cognitive education that takes into account the

limitations of students' **working memory has identified the importance of designing multimedia** learning content **that** does **not**

overwhelm them resulting in increased learning outcomes (Ayres, 2006). Study two examines how a GLAR interfaces' degree of adherence to CTML principles effects students' cognitive load and performance. A single factor repeated measures within-subjects experimental design was used to compare effects on students' cognition after using three GLAR interfaces, each of which created by manipulating the degree of adherence to CTML principles. Twenty-two students were exposed to all three interfaces. Quantitative data revealed that deviations from CTML principles negatively affected students' cognitive load. Results of study two support the assumption that adherence of CTML's design principles is effective in GLAR learning settings. 1.5.3 Objective 3 - Investigate the impact of cognitive style on cognitive performance Researchers, such as Johri and Olds (2011), recommend that learning environments enhanced by technology can be improved by understanding individual differences among students. The literature suggests that researchers can better understand individual differences and account for differences among students by using cognitive styles (D'Mello, Craig, Fike, & Graesser, 2009). Cognitive style is a consistent individual difference characterized by the manner in which students perceive, organize and process information (Price, 2004). Study three examined the impact of designing GLAR interfaces to account for cognitive style differences among students in relation to their cognitive load, performance and learning gains. The study employed

a 2 x 2 x 2 mixed factor **design with one**

between-subject factor and two within-subject factors. Twenty-six students participated where fifty percent of participants were screened

as field-dependent learners **and the other** fifty percent **as field-independent**

learners. The quantitative data affords examination of how students' cognitive style impacts their cognitive load and performance when the voice and coherence principles of CTML are manipulated in GLAR applications. The results of study three aim to bolster the claim that utilizing cognitive style to inform the design of GLAR applications is an effective approach for accounting for students' cognitive differences. 1.6 Significance of Research It is important to acknowledge that as educational and technological fields mature, technology designers need to gain more exposure to educational research studies guided by various educational psychology theories. Even so, because there is a great deal of focus on bringing technology into the classroom, it is crucial that the instructional design supported by AR be based on grounded learning theories (Newstetter & Svinicki, 2014). Although most studies of educational AR applications have claimed increased learning outcomes, these studies generally lack a theoretical basis in educational research. Along with grounding AR applications in learning 14 theory, researchers must further consider the cognitive effects that AR technology will have on students' potential learning gains. This research will provide a novel base of knowledge for researchers, designers and practitioners to consider when creating GLAR applications. This in turn will ensure that resulting GLAR applications support effective cognitive processing and help students learn more efficiently. CTML theory appears to be well-suited to ground AR applications because it reveals how well students can process information based on modality and representation of concepts. It promises to offer designers some guidance to design AR that aims to reduce cognitive load and focus students' attention on vital information while processing the learning content. However, to our knowledge, no other work has applied CTML to AR learning settings. Thus, this research provides contributions to the field that include empirical evidence on the degree to which CTML is effective as an AR-based pedagogical tool. And moreover, provides empirical data on

the relationship between students' perceived benefits **and the impact** of GLAR **on** students' **cognitive load.** Since **the**

opportunity to leverage GLAR in the classroom has not been fully realized, this research will further offer recommendations to consider when creating GLAR applications. By following these recommendations, GLAR designers will increase the likelihood of having a positive effect on students' cognitive load which in turn likely contributes to students' ability to actively process information. The findings from this research will inform designers consideration of the assumptions of CTML when designing AR applications and, ultimately improve students' learning experiences without overwhelming them. CTML does not explicitly take into account individual differences and cognitive development of students. Most research conducted on the assumptions and principles of CTML 15 was conducted with college-aged participants (McTigue, 2009); therefore, this research will determine whether the same benefits can be generalized to other populations such as underrepresented students in 5th grade classrooms. By applying CTML and its principles, this work reveals how AR can be leveraged to meet the educational needs of students in fifth grade classrooms, and especially those at Title I schools. Rather than attempt to change the actual material that students learn, this research aims to enhance the way students learn by enabling tangible and interactive experiences in gamified AR environments. Since fifth grade is one of the formative years for students,

it is important to reduce students' **cognitive load so** they **can**

learn how to select, organize and integrate the learning content to achieve their maximum learning potential. Furthermore, quantifying the strengths and challenges of GLAR with respect to an established theoretical framework will reveal how AR may be utilized

in the classroom to meet the needs of students'

cognitive strategies. 1.7 Dissertation Overview This dissertation uses the manuscript format to present the body of research. Chapter 2 summarizes the current literature on educational AR, gamification and the theoretical framework guiding this research. Chapter 2 also provides a critical assessment of related research to highlight gaps in the field. Within each of the following three chapters (Chapter 3-5), the methodology utilized in the study, data collection and analysis of the data, results, study findings, implications and conclusions are discussed. Chapter 3 describes students' experiences with the GLAR application and their perceived, as well as measured cognitive effects. Chapter 4 investigates to what degree CTML can provide effective theoretical guidance for designing GLAR applications to reduce cognitive load. Chapter 5 examine the cognitive differences amongst students and the effects of cognitive styles on cognitive load. Chapter 6 provides recommendations as well as design considerations to assist with the development of future K – 12 GLAR applications. 2 Literature Review 2.1 Gamification The use of technological innovations is constantly being incorporated in classrooms. The 2013 State of Online Gaming Report hypothesized that

more than 1.2 billion people would play games on computers, tablets or smartphones

by the end of 2013 (NewZoo, 2013). According to Jane McGonigal in 2011, "over a half billion people played video games for at least an hour a day and over five million people in the US alone play games for at least forty hours a week" (McGonigal, 2011). With these statistics, it is apparent that there is something about gaming that captivates and engages people of all ages. Business and marketing industries started the concept of gamification by using elements such as avatars, leaderboards, progress bars, badges, and trophies to capture attention and change the behavior of their users (Linder & Zichermann, 2010; Zichermann & Cunningham, 2011). In 2002, Nick Pelling was searching for a way to make electronic transactions efficient and fun. In the process, he found a way to use user-interfaces that resembled a game and coined the term gamification (Pelling, 2011). He simply defined gamification as "the use of game-thinking and game mechanics to solve problems"

with the end- goal to motivate the user behavior (Deterding et al, 2011). However, the definition **has been expanded** over the years **to**

use game elements or

anything that invokes the same reaction that games do

in a non-gaming environment to impact motivation (Deterding, Dixon, Khaled, & Nacke, 2011;

Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011; Johnson et al., **2013; Domínguez et al., 2013).**

Some researchers describe gamification as “a process of enhancing a service with affordances for game-like experiences to achieve an intended outcome” (Huotari & Hamari, 2011). This process comprises taking an activity that already exists and adds something to enhance the user’s experience. In order to achieve behavior change in a fun and engaging way, there are two important aspects of gamification to consider. The first aspect is stressing the non-game environments that gamification acts upon must carry important resonance for users working in their real life. The second aspect is applying gaming characteristics or structures in which game elements can be applied effectively (McGonigal, 2011). 2.1.1 Gamification Elements Gamification is not solely about developing a game, but instead about applying game attributes to stimulate students, leaving them excited about learning (Arnold, 2014). Some of these attributes that are utilized are gamification elements. Successful gamification depends on several elements to provide feedback and encourage the user to work towards the next level (Morris et al, September 2013; Wood & Reiners, 2012). In the literature there are many gamified elements that can be used in the pedagogical process to make a successful environment for the student. Although there are many elements, Schell believes all are of equal importance and must interact seamlessly (Schell, 2008). The key is to implement the elements thoughtfully as an integral part of the gamified environment. Some of those elements include: Badges: A visualization of rewards that represent skills, knowledge, achievements and other desirable behaviors of traits the user as they accomplish certain goals. Badges should impact the social aspect of the environment as it motivates users extrinsically

(Robson, Plangger, Kietzmann, McCarthy, & Pitt, 2015). 19 Storytelling: **A** sequence **of** events **that**

builds upon one another to create a story. Students are most satisfied when the story is clear, simple, and they can build on and learn from previous events (Deterding, 2011). Levels: A benchmark or objective consists of increasingly difficult levels that users work towards that provides feedback on their progress. Levels should provide short-term goals for the user that promotes the practice of new skills and knowledge while they demonstrate mastery (Robson, Plangger, Kietzmann, McCarthy, & Pitt, 2015). Score: Points that are gained by the user for accomplishing specific tasks. The point system should be a way for users to track their progress as they achieve certain goals (McGonigal, 2011a). Feedback: Information designed to induce a behavior, thoughts, or actions of the user. Feedback should provide users with a timely response to help them adjust and stay on the right track to achieve goals (Kapp, 2012). Progress: A tracking bar to indicate a user’s advancement towards a certain goal. The tracking bar should appear publicly to the user to remind them

how many tasks are left and/ or **how many accomplishments they have achieved**

(Costa, Wehbe, Robb, and Nacke, 2013). Freedom to Fail: Permission for the user to fail multiple times with minimal consequences so they can reconsider their approach to the certain goal. Freedom to fail should reduce the anxiety of the user and make winning more pleasurable (Abramovich et al., 2013; Jovanovic & Devedzic, 2014). A great gamified environment asserts and intertwines the game elements into the non-gaming environment to provide an engaging experience. Understanding and effectively applying these elements will help increase student engagement and limit the novelty effect of gamification (Farzan et al., 2008, Koivisto & Hamari, 2014). Through the heightened use of these elements (i.e., points, levels, badges, etc.), research shows positive potential for increased engagement in fields such as exercise, healthcare, business, and education (Hamari et al., 2014; Kapp, 2012a, 2012b; Zichermann & Cunningham, 2011). 2.1.2 Gamification and Education After observing the positive benefits of gamification in the corporate and marketing fields, game designers such as Gabe Zichermann (2011) and Yu-Kai Chou (2014) explored how gamification could be leveraged in the educational realm to transform learning. Gamification could be easily applied to the educational market through activities such as points, storytelling and badges (Leaning, 2015, p. 160). The benefits of applying various game elements, incentivized point systems, or leveling up prove be effective pedagogical approaches in education (Deterding, 2011). It has the potential to increase positive feelings by applying gamification elements to increase students' learning outcomes (Kapp, 2013). According to Knapp, rewards, such as point gain, levels, and feedback, could improve students' motivation

and engage them **in a meaningful learning process (Kapp, 2013).** In **the**

education, gamification is utilized to maximize students' motivation and engagement by captivating their attention

and inspiring them to continue learning initiatively **(Huang & Soman, 2013).**

For maximum engagement it is important not to confused gamification with game-based learning. Game-based learning utilizes pre-established games or learning based simulations in their complete form to accomplish learning objectives, whereas students play games to learn content (Nolan & McBride, 2014). The difference is gamification does not necessarily involve playing games and use learning as a starting point so students "learn as if they were playing a game" while

game-based learning use an actual **game as the starting point** then **apply learning concepts to it**

(Simões et al., 2013, p. 348). Essentially, gamification is a "non-gaming environment that applies 21 gaming elements" with purpose while game-based learning emphasizes using games as the starting point of instructional purposes (Draeger, 2014). Since its conception, a plethora of studies have been conducted on gamification to explore its contextual definition as it pertains to education

(Deterding et al., 2011; Erenli, **2013; Hamari et al., 2014;**

Teräs, Teräs, & Reiners, 2014). The most used definition of gamification in education literature is given by Kapp (2012) which states that gamification is "using game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems" (p. 10). Researchers believe that in education, gamification is a way of creatively incorporating educational play in a course without jeopardizing the academic rigor of a curriculum (Deterding, Dixon, Khaled, & Nacke, 2011). Literature states that student motivation is increased when game-like characteristics are applied to an academic curriculum that assists students to learn more efficiently (Cheong, Filippou, & Cheong, 2014; Lee & Hammer, 2011). 2.1.3 Implications

The U.S. Department of Education once stated that "educational gamification has the potential to move the dial on student engagement, time-on-task, and student outcomes" (U.S. Department of Education, 2012). The application of gamification

in an educational setting has been cited **to improve** critical thinking **and**

multi-tasking, as well as develop other important skills necessary for students of this generation to be successful (Kapp, 2012b; Prensky, 2001; Shapiro, 2015a). Leveraging gamified characteristics in education will play a major role in shaping curricula and increasing engagement. The lack of student engagement could lead to higher rates of academic failure and students not reaching their maximum learning potential (Busteed, 2013). In 2014, Hamari, Koivisto and Sarsa investigated the effectiveness of gamification in education through a systematic literature review of empirical studies. The investigation indicated 22 that gamification provides positive effects on students' engagement, satisfaction, lessening of disruptive behavior, increased cognitive growth and improved attention spans (Abramovich, Schunn, & Higashi, 2013; Busteed, 2013; Seaborn & Fels, 2015, p. 20). However, these positive effects may vary depending on the implementation of gamification. Hamari found that if educators leverage gamified principles such as continuous challenges, interesting storylines, flexibility, rewards and a combination of realism, fun and imagination, then students would accomplish the said results. From the literature review, the most popular game elements used were badges, points, and feedback (Bartel & Hagel, 2014; Giannetto, Chao, & Fontana, 2013; Holman, Aguilar, & Fishman, 2013; Morrison & DiSalvo, 2014; Thomas & Berkling, 2013; Todor & Pitica, 2013). While there have been many studies that support gamifying education, there are some concerns and criticisms were some studies that showed no statistical benefit (Erenli, 2013; Hamari et al., 2014; McGonigal, 2011a). They showed no statistical effect because the studies evaluated the collection of components together instead of isolating the individual components of gamification to understand effects. The need for more empirical studies

to determine which gamification elements **are contributing to the** increase in engagement, **which are ineffective, and which** have a **negative**

effect on students' achievement is evident

(Borges et al., 2014; Dicheva et al., 2015; Hamari et al., 2014). Also, most of **the**

literature on gamifying education has presented examples where gamification was either used in high school or higher education settings as a motivator for improved student engagement. Few studies investigate the impact of a gamified environment in elementary education (Hamari et al., 2014). Unfortunately, there also seem to be little research on the pedagogical approach to curriculum design and how using gamification in education, with little theoretical grounding is dependent on the instructional context (Bahji

et al., 2013; de-Marcos et al., 2014; Domínguez **et al.,**

2013). The studies evaluating gamification in education is limited; therefore, more empirical studies are needed to address these several shortcomings and gaps in the literature. Although there are some limitations, the literature supports that gamification is a new and exciting way to motivate and positively affect students. Similarly to AR, the

goal of gamification is to improve learning, **not** change or **replace it**

(Landers, 2014). Kapp recommends that a well- designed gamified environment provides a representation of reality with hypothetical or imagined details, which closely aligns with AR (Kapp, 2011). Combining these two concepts allow for students to become active participants in the learning environment while learning contextually

so they learn how to apply abstract ideas in meaningful ways **and**

increase cognitive recognition (Van Eck, 2006; Carnes, 2011). These concepts encourage exploration, reflection, and individual construction of meaning to promote engagement and deeper understanding of the content being presented (Galarneau, 2005, p. 2;

de-Marcos et al., 2014; Domínguez et al., 2013).

2.2 Augmented Reality Virtual reality (VR) is the technological predecessor of augmented reality (AR). VR replaces the

real environment with a simulated **environment,** where **AR** adds **virtual information to the user** environment (Burdea, 2003). **According to**

Milgram and Kishino (2015), AR and VR are closely related, but they

reflect different levels of user immersion in environments where real **and** computer-generated **objects co-exist**

(Milgram et al., 1995). In environments created by VR, users are completely immersed and cannot interact with the real world around them. Chang (2010) believes that VR increases motivation of students participating in educational practices which improves learning (Chang et al., 2007). As the demands of education evolve, there is a need for students to be more involved with their physical learning environment and the technology (Brown, 2006). A solution to this need is utilizing

both the virtual objects **and the real world,** which led to **the** creation **of**

AR. AR is an interactive system that blends the real world and virtual world by utilizing computer elements to provide an additional layer of information over the user's physical environment. AR is

in the middle of a **continuum called mixed reality** (Milgram, 1994). Mixed **reality,**

shown in figure 1, is the incorporation of virtual and real

worlds to create new environments so users can interact with real and virtual objects (Milgram,

1994). AR places digital computer- generated elements such as images, animations, and 3D models and/or sound directly on the user's view of the real world in real time. Kapp and Balkun (2011) states that with AR the real-world environment is enhanced by adding digital content because it allows users to be engaged in the real world while also receiving virtual information at the same time (Kapp, 2011). Chan and his colleagues (2012) emphasize that AR "supplements reality rather than replaces it" (Chang et al., 2012). Furthermore,

Kipper and Rampolla (2013) reported that AR takes virtual information such as video, or touch sensations and overlays them in a real environment

so the worlds become one (Kipper & Rampolla, 2013). The user is now able to co-exist with the virtual information and learn from it

without being completely removed from the physical aspects of the real world (Kapp & Balkun, 2011).

Along with becoming one, combining the real world and virtual objects allows students to visualize abstract concepts to make them concrete. Figure 2: Virtually Continuum (Milgram & Kishino, 1994) According to

Azuma (1997), AR systems are characterized by three properties: "(1) Combine real and virtual objects in a real environment. (2) Align real and virtual objects with each other. (3) Run interactively, and in real time." (Azuma,

1997). Azuma emphasizes spatial registration and believes that without the two worlds, i.e., virtual and real world, being aligned that the AR application will not reach its full potential (Azuma, 1997). The full potential of AR, as opposed to VR, is the user's ability to participate in the real world that is supplemented with virtual objects. 2.2.1 Augmented Reality Types Some of the technological advantages of using AR over VR is the decreased processing power and

increased registration requirements in order to align the real world with virtual

objects. According to Van Krevelen and Poelman (2010) there are three technological categories: handheld, head-worn and spatial. Handheld devices are light weight and simpler to render digital computer-generated elements. Due to their portability, low-priced point and ease of use, handheld devices make AR accessible in more settings, including the classroom (Van Krevelen & Poelman, 2010, p. 4). Head-worn devices are attached to the user's head and render digital computer- generated elements directly to the eyes. Since these devices are more powerful, HMDs are heavy and may need to be connected to a computer. This restricts mobility and it is not easy to use in the 26 classroom. Spatial devices utilize GPS positioning and the device location to display specifically placed digital computer-generated elements in the environment (Johnson et al., 2010). According to Kapp and Balkun, the position-based applications recognize spatial positioning and compare the virtual elements from a "library" of elements stored in the device and overlays

that element on to the real-world (Kapp & Balkun, 2011). Although spatial devices are costly, they allow for unconstrained mobility in the classroom. The level of immersion in an interactive AR system depends on the technology utilized. Another classification for an AR system is whether it utilizes a marker or marker less based AR systems (Johnson et al., 2010). Similar to a spatial device, marker less AR systems detect the real world by using GPS, sensors and device's camera to place the virtual objects in a specific place. This system tracks

an object in the real world without using a marker.

A marker contains programmed information such as text, images and 3D models that can be seen by using the camera on a computer or mobile device. Each marker has

a unique pattern so when the camera views the marker,

it reads the programmed information

that is embedded in the code on the marker

and render specific digital computer-generated elements on the screen (Madden, 2011). Once programmed, the marker can be placed anywhere within the field of view of the camera and the information will appear. If the marker is moved, the information being rendered

will move as well, allowing the user to view the

digital computer-generated elements from different angles (Hubbard, 2009). 2.2.2 AR in Education As the demands of education evolve, there is a need for students to be move involved with their physical learning environment and the technology (Blagg, 2009; Dunleavy et al., 2009). A solution to this need is utilizing

both the virtual objects and the real world, which led to the creation 27 of

AR. According to Dunleavy (2014), AR is defined as "combining the real and a virtual world, seamlessly." An AR environment that seamlessly integrates the virtual and real world can increase learning gains by allowing students to interact with an intuitive interactive system where they can manipulate virtual information while participating in learning activities

in the classroom. Gelenbe et al. (2005) found that allowing students

to experiment with virtual objects increased their understanding of concepts and problem solving skills. The EDUCAUSE Learning Initiative (2005) believed AR

has the potential to enhance school curriculum across the nation and make the learning experience richer by allowing students to become active participants in the learning process. For instance, the manipulation of models allows students the opportunity to learn at their own by actively interacting with real environments and augmented information. They can immerse themselves into the learning content to identify

spatial relationships and orientation **among objects.** This **helps** students gain **a** richer **understanding of the**

learning content and improve on their problem solving skills. They will also be able to interact with their peers, which provides the opportunity to facilitate collaborative learning (Billinghurst, Weghorst, & Furness, 1998). According to Furness, Winn, & Yu (1997), the "degree of immersion is a very important implication for education." A high degree of immersion generates a more authentic learning environment, in which increases students' sense of presence and engagement in such an environment. Here, presence is defined by Witmer and Singer as a students'

subjective experience of being in a virtual **environment (Witmer & Singer, 1998). Winn (2002a)** stated **that**

"the higher the presence the students have the more engagement and involvement the students feel when they act in the virtual environment. As a result, the students learn more from observing the space around them. The reason for this phenomenon is that when students are more engaged in the virtual 28 environment, they are more motivated to interact with the environment, thus resulting in higher levels of learning" (Winn, 2002a). AR has particular features that require students to think critically. According to Winn and Jackson (1999), when students manipulate objects in a virtual environment it helps them to "distribute cognitive activities" and improve decision making skills. Students using their bodies to directly manipulate AR objects plays a significant role in cognition embeddedness and provides them with "sensorimotor feedback" (Shelton, Hedley, 2004). Winn (2002) claimed that in a virtual

learning environment, cognition is embodied in our physical action.

In the 2011 Horizon Report, Johnson et al. note that students can use AR to create knowledge by gathering and processing information by moving from one location to another. By physically interacting with their surroundings, students can connect their learning to the real world which increases knowledge retention

through multiple sensory experiences (O'Shea, Mitchell, Johnston, & Dede, 2009).

As an educational medium, AR increases learning through manipulation, immersion, and active participation activities. Krocker (2012) remarks that "AR can become the fundamental user interface for 21st century learners". Therefore, researchers must examine the effectiveness, benefits and challenges of utilizing AR in an educational context. 2.2.3 Limitations Although AR has the potential to transform education,

there are a few limitations that hinders **the** technology being **integrating into the classroom.**

The EDUCAUSE Learning Initiative (2005) suggested several barriers when implementing AR in an educational environment i.e., cognitive overload, novelty effect, and limited authoring tools. Cognitive overload is when cognitive processes aroused by a learning activity

exceeds the processing **capacity of** the **working memory (Mayer & Moreno, 2003).**

Many researchers have reported that students feel overwhelmed using AR applications due to inappropriate presentation of learning content or high complexity of the learning content being presented (De Jong, 2010). Because of these issues, students experience cognitive overload and the inability to self-guide themselves to engage with the learning content using AR applications. When a student experiences cognitive overload, their understanding of the material being presented is greatly demised. To properly deliver learning content without overloading students' mental capacities, the AR application should properly be paced so students do not rush through the learning material and provide guidance on working through the learning material without being redundant (Dunleavy et al., 2009). Researchers concluded that some of the interest and excitement surrounding educational AR could

be associated with **the novelty of the technology (Di Serio, et al., 2012).**

According to Tulving and Kroll, the novelty effect is a phenomenon that is observed in human performance when special treatment or attention is given to new technology. Although the novelty of AR may have an influence on students, it can be overcome by fostering positive class interactions, collaborations, creating authentic learning environments and mental models as well as longer exposure to the material (Vincenzi et al., 2003). Another limitation of designing educational AR is the available authoring tools.

Most of the current tools are complex, difficult **to** maintain **and**

may require specific or customized hardware. To help researchers and educators develop their own AR applications,

some developers have released free **source code (Krosinsky, 2011).** These **open-** sources **programs**

are important because typically developers are not educators so it provides them with the opportunity to be 30 included in the design process and add educational value to the learning content being delivered (Laurence, 2010). Understanding the limitation of utilizing AR in an educational environment is essential for researchers as well as designers of AR applications if they want to truly enrich the learning environment. Simply engaging students in collaborative activities and evaluating their conceptual learning is not enough (Dillenbourg, 2002). Therefore, researchers need to provide effective AR applications that engage students beyond the novelty effects, reduce cognitive load, and promote continuous learning. 2.2.4 Conclusion AR is a captivating technological tool that allows students to manipulate virtual objects and see multiple representations and perspectives. Researchers believe that with these attributes of multimedia learning, AR has the potential to be an assist to the educational community (McLellan, 2003). However, further research is necessary to find the most appropriate instructional design approach for AR. According to Dede, without appropriate instructional design principles AR is useless and will not meet its full potential (Refsgaard & Henriksen, 2004). The research suggests

that it is not AR itself that is important, but the added value it brings to the

learning environment when it is grounded in a theoretical framework. CTML is a theory, which provides

a framework to help guide the design of multimedia

technologies such as AR. Many researchers believe that leveraging the principles and strategies of CTML in the development of AR is just as important as or more important than the AR itself. Therefore, the next section will crucially review CTML, its principles and how it can be utilized to add educational value to AR as an instructional delivery tool. 2.3 Cognitive Theory on Multimedia Learning Recently, technology has been used in the classroom to combat students' lack of motivation and engagement in tradition classrooms. These technologies have the potential to do more than increase engagement, motivation, and collaboration; they could completely change the overall experiences of students due to the deviation from tradition classroom instruction. In order to maximize the effectiveness of technology such as GLAR applications, the design should minimize students' cognitive loads and positively impact cognitive processing. Research states that cognitive theories such as Paivio's dual coding theory, Chandler and

Sweller's cognitive load theory (CLT), and Mayer's Cognitive Theory of Multimedia Learning

(CTML) focus on the mental processes of students so they can actively process information and rebuild their cognitive architecture. Chandler and Sweller's CLT presumes that within the learning process, "the interaction between limited working memory and organized existing information stored in long-term memory may lead to the risk of cognitive overload" (Sweller, 2005; Sweller, Van Merrienboer, & Paas, 1998). To eliminate students experiencing cognitive load, the technology should control for

two types of cognitive load by effectively presenting learning content that meets students' needs (Sweller, 2005; van Merrienboer & Kester, 2005). Total cognitive load is comprised of

intrinsic, extraneous, and germane cognitive load (Sweller, 2005).

Intrinsic cognitive load is affected by the difficulty level of the students while extraneous cognitive load is affected by the presentation and design

of information (Sweller, 2005). Germane cognitive load is students' efforts as they construct mental schemas for constructing knew knowledge (Chandler & Sweller, 1991; Sweller, 2005; Sweller et al., 1998). Mayer's CTML provides theoretical basis for making learning efficient by using principles to minimize cognitive load by reducing intrinsic and extraneous loads while increasing germane cognitive processing. Essentially, CTML frees the students' working memories, which allows them to better process visual and auditory information (Mayer 2005). 2.3.1

Working Memory Mayer (2009) believe **that** "the central work of multimedia learning takes place in working memory" **(p. 62). Working memory**

is the temporary storing of information that can be quickly lost if it is not processed and stored into the long-term memory because of its limited capacity.

Working memory is actively gathering **information from** either the **sensory memory** or **long-term memory** where prior knowledge **is**

stored (Sweller, 2004).

It is important to note that long term memory

does not have any capacity limitation. Working memory allows a student to leverage their

prior knowledge stored in the **long-term memory to** be integrated **with new information** so **schemas are** formed **(Sweller, 1988).**

In agreement with Low and Sweller, other researchers also defined schemas as "a cognitive construct that schematically organizes information for storage in long term memory" (Schüler, Scheiter, & van Genuchten, 2011; Baddeley, 1992; Mayer, 2001). Schemas integrate prior knowledge with bits of information as a single element rather than several huge pieces of information (Sweller, 1994), which makes more use of the limited space in the working memory. Once schemas are formed, they

become larger and more complex **as new information is** incorporated **(Chi, Feltovich and Glaser, 1981).**

According to Baddeley, the theory of

working memory has **three components: central executive,** visuospatial **sketchpad and** phonological **loop,**

or simply put, processing, encoding and retrieving information (Baddeley, 1992). The central executive component selects and organizes information from the GLAR environment; essentially, it controls the student's attention then transfer information into the long-term memory (Baddeley, 2000). The visuospatial sketchpad 33 receives the spatial information being presented while the phonological loop gathers the audio information from the GLAR environment. These dual channels system, which is a temporarily storage location, manages the retrieving and encoding of relevant information that is needed for learn. Although Mayer believes that in order for people to learn, we need to maximize the use of both channels to actively process information

and expand the limit **capacity of working memory,** Baddeley's theory **is the** channels are independent **of**

each other (Paas, Renkl & Sweller, 2004). Utilizing both channels to present information as CTML proposes will prevent cognitive overload and help the student capitalize on their working memory limitations as well as the limitation of each channel (Sweller, van Merrienboer, Jeroen & Paas, 1998; Mayer, 1998). Literature has densely documented the limitation of the working memory. Although majority of the learning process occurs within the working memory, Miller proposes that the central working memory capacity limit at one time is around three to seven pieces of information when

storing information and two to three pieces when **processing information (Miller, 1956;**

Cowan, 2010). Pieces of information could be defined as a picture, numbers, letters, words, audio and/or character. Cowan believes there is also a time limitation of about thirty seconds to seven minutes of working memory capacity for processing depending on the task (Cowan, 2001, 2014). The limitations of time and storage capacities of the working memory provides a challenge for keeping the students engaged and focused. The final limitation is being aware of the ways that the visual and verbal channels work together to process information. Knowing these limitations is important to presenting information to students and applying the principles of CTML to the design GLAR applications. CTML should assist with the processing of information within the working memory. Researchers and

designers have the ability to manage the limitations **of working memory**

through understanding the restraints and utilizing dual-coding (Igo, Kiewra, Zumbrunn, & Kirschbaum, 2007). 2.3.2 Dual Coding Theory Research states the implication of using both channels concurrently to process information rather than one channel alone can overcome working memory limits which is known as dual-coding (Mayer, 2001; Sweller et al., 1998). David Paivio believes that human cognition can simultaneously handle language with nonverbal objects and events (Paivio, 1986). Based on these beliefs, he developed the dual coding theory which reinforces the concept of concurrently processing information. Dual coding theory suggests that the brain process information in two separate cognitive subsystems that handles

two different types of information that may be **stored in** long-term **memory**

if both subsystems are used (Clark & Paivio, 1991; Reed, 2006). One of the subsystems manages the representations and processing of non-verbal sensory information and the second subsystem deals with processing of language, text and auditory sensory information.

It is important to note that although there **are** two **distinct** subsystems, **each**

of the subsystems can retrieve non-verbal, verbal and sensory input (Paivio, 1986; Harskamp, Mayer & Suhre, 2007; McTigue, 2009). Each subsystem has a limited capacity to receive information by sensory perception via the visual and auditory channel. Sensory information that is coded using the visual and auditory channel shape mental models

that allows other **information to be retrieved from long- term memory**

(Brunyé et al., 2006). According to Kobayaski, when information is dual coded there is an increase

in the probability **that** the **information can be** retrieved **from long term memory**

(Kobayaski, 1986). The probability is increased because when a memory is not available in one subsystem, the other subsystem is available to retrieve memory and encode it with the new information (Kuo & Hooper, 35 2004). This retrieval process can facilitate learning by providing students with the ability to process and recall concrete information. Dual coding theory infer that learning concrete information can be simpler for students because it can be conveyed using both text and images. However, abstract information is harder to represent using dual coding, so it could hinder students from forming mental models and slower retrieval of a previous memory from long-term memory (Hanafi, 1983). Slower retrieval hinders students' learning processes because it requires more working memory to comprehend and process new information. To account for the processing of concrete and abstract information, Paivio provides a general framework for educational psychology that defines the role of visual and auditory processing to help facilitate learning (Jonassen, 1996). Research states that information processed using dual coding of the two cognitive subsystems has a positive influence on the learning content being presented to the student (Clark, 1987; Mayer & Sims, 1994; Mayer & Moreno, 1998; Rieber, Boyce & Assad, 1990). By conducting empirical studies, researchers found that dual coding integration of information when verbal and nonverbal information is presented together produce more learning advantages than singularly using repetition (Najjar, 1995). Many researchers have supported the dual coding theory and have reported the benefits of leveraging the theory to enhance the learning environment. Particularly, Mayer used Paivio's dual coding theory to influence the development of CTML. Similar to Paivio, Mayer believes that well-designed instruction that presents information in both modalities can leverage the two cognitive subsystems, which should increase learning gains (Mayer et al., 1999).

Since multimedia learning **deals with** the **visual and** auditory channels, **dual coding theory** provides limits for **the**

amount of information students can process in either of the channels at any one time without overloading their cognitive systems (Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). CTML addresses how using two cognitive subsystems to process information allows for encoding at a deeper level than just using one subsystem which increases students' performance in memory retrieval tasks (Mayer, 2009). Since GLAR applications can provide students with both visual and auditory information, it is important to understand how they use both channels to process information, form mental models, and learn with the application. 2.3.3 Cognitive Load Theory Researchers acknowledge that working memory

can only process a finite **amount of** information at **a given** amount of **time while long term memory has** endless **capacity for**

permanent storage new information (Sweller, van Merriënboer, & Paas, 1998; Miller, 1956; Simon, 1974; Clark, Nguyen, & Sweller, 2006). CLT investigates the cognitive architecture of the human brain that aligns to how effective learning and understanding of new learning content happens to prevent overload of a student's limited working memory. Overload occurs

when working memory does not process new **information due** lack of sufficient **cognitive**

resources which hinders learning (Chandler & Sweller, 1991; Sweller, 1999). Sweller argues that

in order for maximum **learning to occur the** limitations of **working memory**

needs to be addressed to help students' process new information and integrate in long-term memory. Therefore, CLT provides a framework for how to efficiently present information so new information can

be processed in working memory and **stored in long-term memory**

through schema construction (Paas, Renkl, & Sweller, 2003). According to Paas and Sweller, if the available capability of the students' working memory is exceeded

when new information is presented they will **experience cognitive load** (Paas & **Sweller,**

2012). Cognitive load is "the amount of information the working memory can hold at a given time" (Cooper, 1998). Whereas mental effort is the cognitive capacity spent on completing 37 a task (Sweller, 1998). Within

working memory there are three types of total **cognitive load: intrinsic** load, **extraneous** load, **and germane**

load (Sweller, 2010; Sweller, 1994). All these loads

have an impact on cognitive load and the limitation of **working memory**

capacity (Paas, Renkl, & Sweller, 2003). Although

intrinsic and extraneous load are additive, the combination **of** all **the**

loads should not

exceeded the capacity of working memory (Paas, Renkl & Sweller, 2004). **If**

total cognitive load is exceeded while trying to complete a task, learning can be jeopardized. This capacity of working memory varies for each person that why it is important to control each of the loads. These loads will be further explained below and how to control these loads.

Intrinsic Cognitive Load: Intrinsic cognitive load is one's **level of difficulty**

that is

defined by the natural **complexity of the information** they must learn **(Sweller, 1988).**

This load allows the processing of information to happen simultaneous which is necessary for understanding to occur. Sweller indicates that

intrinsic load is based on the number of interacting pieces of information that has to be processed in the working memory. A

piece of information is defined be any type of learning content, information or schema that is processed by working memory (Sweller, 2010). If there is an increased in

pieces of information or the relationships between pieces of information

is too complex there will be more intrinsic cognitive load imposed on working memory (Sweller & Chandler, 1994; Paas, Renkl, et al., 2003; Gerjets, Scheiter, & Catrambone, 2004). Since students process information differently, intrinsic cognitive load is unique to each student (Kalyuga, 2005). However, low level of element interactivity will reduce intrinsic load for all students. It allows the elements to be processed in segments so students do not have to keep them all

in working memory at the same time (Leahy et al., 2003). Pollock, Chandler, and Sweller

argue that intrinsic

load cannot singularly be reduced by instructional design because it is dependent on the complexity and number of

new information being presented (Pollock, Chandler & Sweller, 1998). Nevertheless, assimilating information into smaller pieces to be processed separately

has been shown to manage intrinsic cognitive load (Moreno, 2007; Mayer et al.,

2003).

Extraneous Cognitive Load: Essentially, extraneous cognitive load is the strain placed on working memory processing by having the

students select, organize and integrate unnecessary information (Sweller et al., 1998). Extraneous load is affected when information is ineffectively presented to students (DeLeeuw & Mayer, 2008). Ineffective instructional design introduces

unnecessary information that is not needed for learning to occur

which increases extraneous load (Bannert, 2002; Sweller, 2005). Although information or elements can be presented in multiple ways, it is essential that relevant only information is presented and grouped closer together in time and space, so it reduces the demands on working memory and

extraneous load. By reducing extraneous load, it provides more working memory for students to understand and construct new schemas (Paas, et al., 2004; Sweller, 1993). This load is also dependent on the prior knowledge of each student (Sweller, 2010). If the information depends greatly on students' existing knowledge, it diverts working memory capacities away from creating new schemas and increases extraneous load (Mayer et al., 1995). Thus, a plethora of CTL research is

focused on how extraneous load affects students **and how it can be reduced through**

effective instructional design. Extraneous cognitive load should minimize the information gathering and filtering process to increase

schema construction. Germane Cognitive Load: Germane **cognitive load is** cited in **the**

literature as the most ideal or effective load that leads to understanding of information while intrinsic and extraneous cognitive loads impede understanding (Mayer & Clark, 2010; Sweller, 1994). Germane cognitive load is needed for integrating new information with existing schemas

in working memory then storing **it in long-term memory**

(Kirschner, 2002). According to Kalyuga, germane load is the amount of resources allocated for processing after accounting for

intrinsic and extraneous load **(Kalyuga, 2011; Sweller et al., 2011).**

Germane cognition can only be obtained when there are available working memory resources. Therefore, it is imperative

that intrinsic and germane loads are managed adequately so **the total** cognitive **load**

is not exceeded and its available working memory resources for more schema construction (Kalyuga, 2011; Mayer, 2009). Therefore, the instructional designers should take advantage of free working memory resources to foster generative processing which contributes to effective learning. Sweller believes germane load results in deeper learning when the student effectively use their working memory resources to attach

new information to existing knowledge stored in long-term memory

(Sweller, 1998). Mayer suggests engaging

in the selection, organization, and integration of the information

by using guiding and pacing techniques. The primary goal of CTL is to enhance germane load and focus on the processing, construction and automation of schemas which is necessary for students to learn (Paas & Sweller, 1998, p. 265). Sweller initially believed learning could only be improved by reducing

extraneous load (Sweller, 1988). **When extraneous load is reduced,** more of **the**

available

working memory resources can be dedicated **to** additional **information processing (Heo & Chow, 2005).**

However, recent literature suggests that since intrinsic load cannot be managed the aim is to maximize germane load

in addition to reducing extraneous load, which promotes processing **in working memory**

(Mayer, 2012; Sweller, 2010). If intrinsic and extraneous loads are both high, there are no resources for germane load and the limited capacity in working memory may be overload. Thus, in order to prevent cognitive overload all three loads needs to be managed appropriately so that learning is more efficient (van Merriënboer & Ayres, 2005). When total cognitive load cannot be properly managed, learning may not happen because there are no available resources to allocate for processing (Sweller et al., 2011). CTL is a learning or instructional theory that explains how to improve the cognitive processes of students while they are

learning (Cooper, 1998; Brunken, Pass, & **Leutner, 2003; van Merrienboer & Sweller, 2005).**

It accounts for the human cognitive infrastructure by assuming the capacity of working memory is limited when people learn (Sweller, 2005). Essentially, CTL's objective is to provide a framework that improves student learning by effectively presenting learning content. Thus, accounting for the three types of cognitive load, which manage limitations of their working memory, so students are not cognitively overwhelmed. CTML leverage notions of CTL to understand how information is perceived and processed in working memory using dual modality (Kombartzky, Ploetzner, Schlag, & Metz, 2010; Reed, 2006). 2.3.4 Cognitive Theory on Multimedia Learning Technology is being increasingly applied in K-12 environments to enhance student learning. However, extensive research on how

technology can be incorporated **in the classroom to** enhance cognitive **learning** and development has **not**

been done (Mayer & Anderson, 1991; Sorden, 2005). To fill the theoretical gap, Richard Mayer and other researchers conducted empirical research on how specific design techniques could improve learning. From these studies, Mayer realized that the available theories were not examining students' cognitive processing; he developed CTML which is an educational psychology theory. CTML was created to include the results of empirical studies influenced by dual coding theory and cognitive load theory, which was discussed in previous sections, as a theoretical framework. These theories are the basis on CTML that support the concept of working memory having limitations and the brain effectively processing information using both the auditory and visual channels. Sweller believes cognitive 41 load happens when material being presented is organized effectively so the student can focus and not use unnecessary cognitive resources (Sweller, 2010). Paivio noted that research was needed to address the cognitive load limitations that students may experience when working with technology (Paivio, 1998). CTML explains how using technology people process information through visual and auditory channels and

integrate it with prior knowledge already stored in long-term memory to

form new connects. Although CTML was first created in 1997, it has been expanded over the years to account for the types of cognitive load of students will encounter when learning. CTML attempts to decease

extraneous processing, foster essential processing, and enhance generative processing while promoting active learning (Mayer,

2009). Fundamentally, CTML was developed

based on three assumptions: dual channel assumption, limited capacity assumption, and active processing assumption (Mayer, 2005). The dual channel assumption states that students have two separate channels (i.e. auditory and visual

channels) in working memory that processes visual and auditory information. This assumption is based on the Baddeley's dual coding theory which explains how utilizing both types of information reduce the demands of working memory. Mayer believes the two channels work together to create cross-channel representations and foster intrinsic load (Mayer, 2005). The dual channels gives people the opportunity to build verbal and visual mental models simultaneously which produce increased learning gains. The dual channel assumption supports the fundamental claim of CTML

that people learn best when visual and auditory information are presented simultaneously rather than

words or images alone (Mayer, 2012). The second assumption of

limited capacity is based on two theories: cognitive load theory and

dual coding theory. Both theories state that each channel in

working memory has a limited capacity and students can only process a certain amount of information at a given time (Mayer & Moreno, 2003; Baddeley,

1999). CTML claims that if working memory limits are exceed then generative processing increases and hinders learning. The final assumption of CTML assumes that to effectively learn a student is actively processing information (Mayer 2005).

Cognitive processes are required to make sense of the information being presented

so mental models can be created; therefore, enabling generative processing (Wittrock, 1974). Mayer proposes that the outcome of active learning leads to students' ability to select, organize, and integrate new information with existing knowledge,

so coherent mental representations can be constructed (Mayer & Moreno, 2002; Mayer & Moreno, 1998). According to Mayer, active learning happens when students participate in five cognitive processes: selecting relevant visual information, selecting relevant audio information, organizing the select visuals, organizing the selected audio, and integrating visual and auditory information with one's

prior knowledge that is stored in the long-term memory

(Kalyuga, 2011; Kombartzky et al., 2010; Mayer, 2005, 2009). These five cognitive processes are necessary for learning to occur. If multimedia is cognitively demanding, students will not be capable of selecting, organizing, and integrating new information because their available working memory capacity would be consumed (Mayer, 2009). During the selection process, the student must determine which information is necessary to learning the material being presented. Once the necessary information is selected it is held in the working memory. According to Moreno, holding auditory and visual information in working memory simultaneously is optimal for constructing mental models (Moreno, 2003). If the new information is too complex, it requires more essential processing. Actively organizing the information uses generative processing which allows for mental models to be created in working memory (Kalyuga, 2011). Mayer states that the integration of the mental models with prior knowledge is a demanding cognitive process (Mayer, 2005). He recommends students build simple mental models that make sense to them, so the process is less demanding.

It is important to note that the five cognitive processes are not

a linear method. Kalyuga states that the student may complete some of the processes multiple times and in any order depending on their prior knowledge, working memory capacity and cognitive loads (Kalyuga, 2011). Understanding and managing the limitations of cognitive loads will lead to deeper learning, retention and meaningful transfer of material being taught (Mayer, 2009). Based on these assumptions, Mayer identifies five

scenarios in which cognitive overload may occur. The sources of

cognitive overload could include many things such as one channel or both channels requiring too much cognitive processing. The first scenario is visual overload where the visual channel is overwhelmed. To reduce visual overload, Mayer suggests offloading some of the visual information to the auditory channel (Mayer & Moreno, 2002). The second scenario happens when both channels (i.e., visual and auditory) are overloaded with too much information. Cognitive load can be reduced by segmenting the information over a duration of time, so everything is not presented at once which allows for cognitive processing to happen. The third scenario is when extraneous or unnecessary background information is presented. Eliminating unnecessary information or directing the student to the essential information will reduce this cognitive load. Presenting essential information in an unclear and disorganized manner is the fourth scenario. This type of

cognitive load can be reduced by presenting material in a logical approach using close proximity. The final scenario is described by Mayer and Anderson as "the loss of information due to the need for storing information in a representational holding pattern during the presentation of additional information" (Mayer & Anderson, 1991, 1992). It is important that the additional information does not replace the information being held in the working memory. To reduce this cognitive load the student should have time to encode the first set of information into long-term memory before receiving new information. In each scenario, the suggestion to reduce cognitive load aims to redistribute essential processing and limit representational holding (Mayer & Moreno, 2002). Understanding the limitations of the working memory will improve students' ability to build mental representations of the material being presented (Mayer, 2010). If too much information is provided to student it forces them to utilize too much of their working memory which impedes the learning process (Mayer, 2010). Leveraging CTML in the classroom produce cognitive advantages that cannot be achieved using traditional methods (Mayer, 2005). Muthukumar believes that Mayer's CTML

is one of the key theories in the field of educational **psychology that**

explains students' mental reasoning and how they process new information (Muthukumar, 2005). Although CTML describes how cognitive processes occur in two separate channels to decease extraneous processing, foster essential processing, and enhance generative processing, there are some issues it does not address when leveraging it in empirical studies. According to Wiserma and Jurs, CTML research lacks ecological validity because most studies occur in a highly controlled setting and does not replicate a traditional classroom environment (Wiersma & Jurs, 2013). The results of the controlled setting may not be transferrable to an actual classroom where things are dynamic and unpredictable. Moreover, the generalizability of specific demographics is limited and the results on one target population may not be reflected in the results of another population (Schüler et al., 2011). Although there are some issues, they do not invalidate the findings of CTML. The implementation of this theoretical framework will provide guidance for designers, educators and researchers on how to select and develop multimedia technology that improves students learning. The CTML framework provides design principles that will reduce cognitive load while increasing the retention and transfer of learning content. In the next section, the principles are furthered discussed on how they were established based on results from several empirical experiments. 2.3.5 CTML's Design Principles The overarching aim of CTML is to decrease

extraneous cognitive load, manage intrinsic cognitive load and increase **germane cognitive load. From**

extensive evidence-based research Mayer and his colleagues created several principles to address each cognitive load so student can reach their maximum learning outcomes (Mayer, 2009, 2001). According to Mayer, there are five principle that explain how extraneous cognitive load

can be decreased: redundancy, **coherence, signaling, spatial contiguity** and **temporal contiguity**

principles. To manage intrinsic cognitive load, Mayer identified two principles that could be leveraged in multimedia technology design: segmentation and modality principles (Mayer, 2009). Finally, the personalization principle is utilized to increase germane cognitive load. If the working memory exceeds its limitation, then cognitive overload occurs and hinders student learning. Therefore, the eight principles are used to design appropriate instruction that maximize the students' available cognitive recourse in working memory to ensure the limitations are not exceeded. Signaling: The

objective of the signaling principle is to reduce **extraneous cognitive load by using**

cues so students are able to comprehend the material being presented (Mayer & Moreno, 2003). Highlights, arrows, lines, graying out unnecessary information are examples of cues that are used to reduce cognitive processing in the working memory (Mayer & Moreno, 2003). By using cues, students do not utilize unnecessary cognitive resources locating important information or integrating nonessential information into schemas. According to Mayer, students learn more effectively when cues are used to guide their attention to vital information (Mayer, 2010). Thus, signaling help decrease the amount of searching required to process information. However, if signaling is used when extraneous load is low and intrinsic load is nurtured, it could be distracting and

hinder students' ability **to understand the information** (Harp & **Mayer,** 1998). Personalization: **The** objective of **the**

personalization principle is to design material by accounting for individual differences of students as they process information (Mayer, 2005). Mayer suggests that the use of conversational style rather than a formal style to present information will acknowledge the various learning difference of students (Mayer, 2008). Clark and Mayer also found that students learn better from a human voice versus a computer-generated voice. Therefore, what is said and how it is said are important influences to consider when presenting information. The use of conversational style and human voice allows students to create personal and relevant connections with the information and encourage them to work harder to learn the material (Mayer, 2008). Thus, research suggest that students work harder to understand when they feel they are in a conversation which reduces cognitive load (Mayer, Fennell, Farmer, & Campbell, 2004). The personalized principle provides students with more cognitive resources to focus on the material being presented so schemas can develop. Segmentation: The objective of the segmentation principle is to reduce cognitive load in working memory when complex information is presented (Mayer & Chandler, 2001). The principle claims that students learn better when the information is divided into short segments that they can control rather than continuously (Mayer & Moreno, 2003; Astleitner & Wiesner, 2004). Thus, deeper understanding and reducing cognitive load on working memory happens when the student can integrate the smaller segments they find cognitively demanding into schemas before moving on to the next set of segmented information (Mayer & Chandler, 2001; Mayer, 2009). Mayer (2001) believes that allowing the student time to understand each segment facilitates their ability to make connections with prior knowledge and manage their cognitive load. Although providing students with control over the material can increased learning gains, reduced extraneous load and improve germane load, the segmentation principle should take their prior knowledge into consideration. Previous research studies report that students with higher prior knowledge experienced high intrinsic and extraneous cognitive loads when the segmentation principle was incorporated (Lusk et al., 2009; Park et al., 2009; Tabbers & Koeijer, 2010). Coherence: The coherence principle objective is to reduce extraneous load by eliminating irrelevant visual and auditory information (Mayer, 2005). The inclusion of irrelevant information will cause unnecessary extraneous load on working memory which hinders learning (Moreno & Mayer, 2000). Thus, students learn best when extraneous material is excluded rather than included. According to Clark and Mayer, this is the single most important principle and cautious selection of visual and auditory information is needed to ensure maximum learning outcomes. All information presented should be relevant and support the instructional goals so working memory capacity is available to make connections. Therefore, designers should not add extraneous material in an attempt to “spice up” or make a boring lesson exciting for the student. This may have a negative impact on learning because the extraneous information requires increased cognitive resources and prevent the student from building schemas (Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer et al., 2001; Moreno & Mayer, 2000a). Hence, Mayer suggests taking a minimalist approach in which only the relevant material needed to achieve the instructional goal is included. Redundancy: The redundancy principle objective is to reduce extraneous cognitive load by ensuring unnecessary or similar information is not presented in multiple forms (Mayer & Moreno, 2003). The presentation of redundant information through the visual channel at the same time as the auditory channel will place great cognitive demands on working memory and hinders learning (Sweller, 2004; Clark & Mayer 2003). Thus, redundant or repeated information should be eliminated to reduce extraneous cognitive load and decline the load of the visual channel. Mayer and Moreno believe that if the redundant visual information is not removed it creates an additional step and causes students to attend to both channels which slows essential processing (Moreno & Mayer, 2002). According to Sweller, prior knowledge should be taken into account because when students with higher prior knowledge are provided information they already know, demands are placed on working memory because the schemas students are trying to create are already stored in their long-term memory (Sweller, 2005). Modality: The modality principle objective is to present visual and auditory information at the same time to ensure dual coding occurs (Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994; Paas, & Merriënboer, 1994). Receiving information through dual channels instead of a single channel creates a deeper understanding of material and effectively expands working memory capacity to reduce extraneous load (Sweller, 2005). By expanding working memory capacity, the student has more cognitive resources to process information and create mental models (Kalyuga, 2008). Thus, students learn better when receiving information through multimodality presentation because the visual channel is being off- loaded by some of the processing occurring on the auditory channel. According to Clark and Mayer, the modality principle is beneficial for students with little prior knowledge to organize the new information into coherent representations and integrate those representations with other information to increase learning (Clark & Mayer, 2011). Therefore, the modality principle is most effective when intrinsic load is high and prior knowledge is low. Spatial Contiguity: The spatial contiguity principle objective is to coordinate information is space to lessen cognitive demands on working memory (Mayer, 2005). When information presented through multimodality is place close together, it reduces the cognitive demands in working memory because the students do not need to hold the information in their working memory while they search or wait for to hear or see corresponding information. Thus, students learn better when visuals and text are presented in close proximity rather than apart (Mayer, 2005). Although the spatial contiguity principles reduce extraneous cognitive load by closely placing information together, so students can build representations, it could create the spilt attention effect (Astleitner & Wiesner, 2004). The spilt attention effect occurs when the visual channel is overloaded with too much visual information; therefore, researchers caution designers to only include relevant information, so students are not forced to decide what information requires their attention (Mammarella, Fairfield, & Di Domenico, 2013). Temporal Contiguity: The temporal contiguity principle objective is to reduce extraneous load by have presenting auditory and visual information simultaneously. This principle focuses on the temporal distance of information. Thus, students learn better when multimodality presentation of information is temporally synchronized rather than separated in time (Mayer & Moreno, 2003). Successively presenting information requires students to retain information in working memory while they search or wait to hear or see corresponding material which is cognitively demanding (Fletcher & Tobias, 2005). Therefore, the temporal contiguity principle is needed to reduce unnecessary cognitive load by coordinating information in time. Voice: The objective of the voice principle is to provide multimedia learning instructions using a human voice with a local accent rather than a machine or computer generated voice or foreign machine (Mayer et al., 2003). This principle states that students learn best and can better transfer knowledge from unaccented, human voices (Mayer, 2014). The inclusion of a computer generated voice or foreign accent will decrease students' motivation to engage in deep, active processing of the information perceived and hinder performance on problem-solving transfer tasks. This principle also suggest that people learn more from instructional videos when words are presented in a conversational style rather than a formal style (Kartal, 2010). According to Mayer and his colleagues, a conversational tone has a great impact on a student's ability to transfer their knowledge from the AR application to the new task verses using a formal style (Mayer et al., 2004). Researchers found that utilizing the voice principle increase generative processing of instructions and is driven by the student's processing of social motivational cues embedded in the instruction (Mayer, 2009). Therefore, when thinking about instructional design, including the voice principle will increase the social connection between instructor and the student because social motivational cues have been shown to be a key consideration in improving learning. Instructional design principles were developed by Mayer and his colleagues so educational multimedia technology can effectively be leveraged in the classroom to deliver material to students without overwhelming them cognitively (Mautone & Mayer, 2001; Mayer & Johnson, 2008; Mayer & Moreno, 2002; Moreno & Mayer, 2006). If the eight design principles are implemented properly, visual and auditory information can be presented simultaneously to students to minimize extraneous cognitive load, foster essential cognitive processing, and maximize generative cognitive

processing. The redundancy, **coherence, signaling, spatial contiguity, and temporal contiguity principles**

address design features that reduce extraneous cognitive load (Chandler & Sweller, 1992). Segmentation and modality principles are used to manage essential processing, so students have cognitive resources available to organize information and deeper learning can occur (Sweller, 2010). Using the personalization principle, students' learning outcomes are improved by increasing germane cognitive load (Mayer & Moreno, 2003). The eight principles consider the limitations of working memory, assume of multimodality presentation and the active learning process to provide designers with effective strategies to develop multimedia technology that meets the cognitive needs of students and enhances their learning experience. 2.3.6 Measuring Cognitive Load Since there are many factors that influence cognitive load,

it is difficult **to measure the** amount **of mental effort a**

person exerts while performing a specific task as well as the specific type of load affected. Mental effort is how much effort is exerted by the participant to accommodate task demands while mental load is cognitive demands imposed by the task which is measured using many different techniques. The major techniques cited in the literature are subjective measurements, physiological measurements and task-and performance-based measurements. Mental effort and mental load both contribute to cognitive load. There is a plethora of assessments available that measure specific cognitive load types (i.e. NASA TLX, and subjective rating scales) (Brünken et al., 2003; Leppink et al., 2013). However, the literature states that it is challenging to measure specific

types of cognitive load. Sweller **and** Kalyuga propose **that** specific **types of** cognitive **load**

can be measured by controlling for other types of cognitive load 52 and one's prior knowledge (Sweller, 2011; Kalyuga, 2011). Yet, Kalyuga argues that germane cognitive load can be manipulated since manipulations of germane cognitive load would influence intrinsic cognitive load (Kalyuga, 2012). Choosing the appropriate technique and measurement tool depends on what the researcher wants to measure and must align to the specific objectives of the study (Annett, 2002, p. 984). Below are the following techniques and tools: Subjective measurements are a direct or indirect way to report cognitive efforts using scaled numerical values rating scales by participants (Kalyuga, 2011). These

rating scales provide a premeditated **measurement of** cognitive load **since** the scales **are** completed **after**

the specific task. Paas argues that in order for rating scales to collect accurate data the participants should be capable of reflecting on their cognition and indicating their mental efforts used (Paas et al., 2003). Kalyga claims that since spontaneous measurement is not available, the measure may not be reliable (Kalyuga, 2011, p.15). Subjective measurements are easy to implement and provide high validity results. However, results are sensitive to participants' environment, culture or individual differences which may cause bias and have a hard time distinguishing between the three types of cognitive load. Direct subjective measurements: The participant self-reports their perceived stress level after completing a task. Sweller defines direct measurements as "the rating of the difficulty of the materials", which is directly relates to the cognitive load the participant experienced (Sweller, 1999). Indirect subjective measurements: The student self-reports their perceived mental effort through evaluation of pre and posttests or knowledge assessment to understand material after completing a task. Researchers concluded that if students' performance improve on the posttest then students' extraneous cognitive load was reduced (Clarebout & Elen, 2007; Medula, 2012). This technique is frequently used to evaluate cognitive load; however, researchers found it difficult to explain how mental efforts relates to cognitive load (Paas, 2003). Frequently used subjective measurements are NASA Task Load Index, the Subjective Workload Assessment Technique and the Rating Scale of Mental Effort (RSME). NASA TLX and SWAT are multidimensional scales that have the capability of measuring direct sources of load instead of measuring overall workload. RSME is a simple and direct way to assess mental effort; however, they are less sensitive to overall workload (Kalyuga, 2011). Paas developed the Paas' mental effort

rating scale which was the first subjective tool **that** demonstrate how **people can**

evaluate their perceived mental load using a mathematical number (Paas et al., 2003). According to Mayer, Paas' scale is the most used subjective measure of working memory load within the CTML literature (Mayer, 2009). Objective measurements are performance and behavior measurements to understand cognitive load. Objective measurements can also be collected directly or indirectly. Performance based measures evaluate the overall quality of cognitive load by deriving an index of the user's workload from the participant's performance when completing specific tasks. Researchers assume that high performance is the result of low cognitive load (Brünken et al., 2003). Performance is commonly cited measure of cognitive load that is difficult to differentiate between the three types of cognitive load (Mayer, 2011). Direct objective measurements: Direct objective measurements use physiological and behavioral measures to evaluate total cognitive load through brain activity during a task. Direct objective measurement should be used in a controlled setting with small sample sizes (Tabbers & Van der Spoel, 2011; Whelan, 2007). The limitations of direct measurement are the inaccurate measurement of high order thinking abilities and not being able to distinguish which cognitive load is being affected (Sweller, 2011). If the task requires the student to think critically then direct objective techniques cannot accurately measure cognitive load (Just et al., 2001; Whelan, 2007). Indirect objective measurements: The participant self-reports their perceived level of difficulty and stress (Whelan, 2005). This rating determines the overall cognitive load and specific types of cognitive load affected after viewing information or completing a specific task (Brünken et al., 2003). Indirect objective measures help to measure cognitive load as well as differentiate which type of cognitive load is affected. This is the most commonly method for investigating cognitive load effects. Behavioral and learning outcome measures are the most used direct objective techniques. Another technique involves time needed to solve a problem. According to Bruken, the

more time spent on a particular task, then **the more difficult the**

task is which results in high cognitive load (Brunken et al., 2005). Moreover, he also believed that little time spent on a particular task could result in high cognitive load because the student stops committing cognitive resources to learn (Brunken et al., 2005). The main limitation of this technique is the incapability of measuring distinct sources of load of cognitive load and low sensitivity to changes in the task. Physiological techniques are an indirect objective approach to measure cognitive load by examining the participant's physiological activities. These techniques offer an improved understanding on which of the three cognitive load types is effected following a single or repeated approach or experiment for the same person (Whelan, 2007). Cognitive efforts are measured by evaluating the change in physiological indicators such as heart rate, eye activity, galvanic skin response and brain waves (Whelan, 2007, p. 3). This data is collected continuously and automatically during an experimental study. Although researchers believe changes in cognitive functioning are reflected in physiological indicators, they have some concerns for using this technique (Paas & van Merriënboer, 1994). These measures are invasive, expensive and are difficult to repeat (Luximon & Goonetilleke, 2001). According to Zhang and Luximon (Zhang & Luximon, 2005), this technique may include personal and environmental bias that do not pertain to the task (Brünken, Plass, & Leutner, 2003). Dual task methodology is another objective approach that provides concurrent measurements of cognitive load that requires the participants to complete primary and secondary tasks simultaneously. Since the two tasks are processed at the same time, the performance score after completing the primary task is compared to the score on the primary and secondary

task to determine **the amount of** cognitive load imposed **by the primary task**

during critical thinking activities (Brünken, Plass, & Leutner, 2003). Assuming cognitive demands increase, additional resources are utilized, which will result in increased cognitive load. The additional resources needed to complete the

secondary task would be limited by what is already utilized **on the primary task.**

Selecting and implementing an effective secondary task is difficult for researchers because the secondary task should not intervene with the primary task and both tasks should use the same cognitive resources (Sweller, 2011). If the secondary task is ineffective, it could lead to cognitive overload which decreases primary task performance and increase extraneous cognitive load (Whelan, 2007). Although many researchers have tried to investigate how to quantify cognitive load, a goal standard technique has not been identified (Van Gerven et al., 2004;

Folker et al., 2005; Paas & van Merrienboer, 1993; Tabbers **et al.**

2004). Research concludes that as of now, subjective measurements are the best available techniques to measure mental effort (Zhang & Luximon, 2015). Since direct objective measures are too invasive, subjective rating scales are more practical, cost efficient and effective. Also utilizing multiple measures can be leveraged to enhance the accuracy of measuring mental efforts. Regardless of the techniques used, it is important to accurately measure mental efforts, so students can achieve their maximum workload while maintaining their performance level. 2.3.7 Limitations CTML has developed a theoretical framework that provides guidelines for effective instructional design that consistently have shown positive effects on learning. However, there are a few limitations in the literature when applying CTML, i.e., ecological validity, generalizability, and measuring cognitive load. Many researchers have investigated the effectiveness of combining several of the design principles in a controlled experiment while only a few studies have been done to examine individual principles of design to validate the framework. Highly controlled experiments have produced significant learning gains; however, the results are not generalizable and do not translate to a traditional classroom environment (Tabbers et al., 2004). Many studies address the cognitive needs of students however, it is difficult to measure cognitive load, especially in children, so more studies are needed to address this. Moreover, when designing for children, it is difficult to evaluate their prior knowledge and

account for the differences in prior knowledge of each **individual**

student. In most of the studies, prior knowledge was evaluated using pre- assessments (Mayer, 2010). However, Sweller recommends developing a

more robust assessment **that can alter content presentation in response to the** input and **cognitive changes in**

the student (Sweller, 2005). 2.3.8 Conclusion Research supports that applying the principles of CTML will improve the cognitive processing of students in a technology enhanced environment

(Aldalalah, 2012; Florax & Ploetzner, 2010; Ibrahim et al., 2011; Mayer, 2010).

Mayer leverages other cognitive theories to explain how the human brain processes information. Baddeley's theory of working memory influenced CTML by providing

an understanding of the limitations of working memory and the role **of**

prior knowledge to creating schemas. Paivio's dual coding theory and Sweller's CLT provides techniques to optimize the way information is presented to reduce cognitive overload. The aforementioned theories form the basis for CTML that human information processing uses dual modality channels, which are limited, that allows

for information to be actively organized and **integrated with prior knowledge for**

learning to happen (Mayer & Moreno, 2003; Moreno & Mayer, 2000; Garner et al., 1989). Studies in the literature haven't investigated the role prior knowledge has on the development of schemas in the working memory. The literature also has not addressed which principles are most effective at reducing intrinsic and extraneous loads while increasing germane cognitive loads. To address the gaps and limitation of the literature, this research will use the guidelines provided by CTML to design the GLAR application to account for limitations and the principles to effectively deliver educational content to students to optimize their cognitive processing

(Mayer & Moreno, 2003). 3 Understanding the Role of Prior Knowledge and Students' Perspectives 3.1 Introduction The National Educational Technology Plan of 2010 believes that one of the most powerful ways to transform and improve K-12 STEM education is to instill a culture of innovation through the use of technology (Polly et al., 2010). Recently, technology such as augmented reality (AR) has been used by teachers to combat students' lack of motivation and engagement in traditional classrooms. However, AR has the potential to do more than increase engagement and motivation due to deviation from traditional classroom instruction by completely changing the overall learning experiences of students. Research has shown that, when correctly deployed in the classroom, AR can improve memory recall, kinesthetic and experimental learning, spatial abilities, and increase motivation and collaboration amongst students when compared to traditional classroom approaches (Polly et al., 2010; Morrison et al., 2009; Kaufman & Dunser, 2007). Along with using new novel technology, another way to captivate students is to gamify their learning environments. Through gamification, game-based mechanics and game-like elements are used in a traditionally non-gaming environment to engage students to solve problems and

learn as if they are **playing a game.** Researchers believe **gamification** is **a** way **to**

creatively incorporate educational play in a course without jeopardizing the academic rigor of curriculum

(Deterding, Dixon, Khaled, & Nacke, 2011). With **the** successful usage **of game elements**

(e.g. rewards and leaderboards) the delivery of information in an activity can be transformed into an effective learning environment. The application of gamification in educational settings has been associated with improved critical thinking and multi-tasking, as well as development of other cognitive skills necessary for students to be successful (Kapp, 2012; Prensky, 2001; Shapiro, 2015). Although learning can be enhanced by implementing technology in the classroom or by gamifying the learning environment,

it is important to take into account established learning theories **that** support how **students**

learn (Kirkwood & Prince, 2005). Before implementing a new technology such as gamified AR in the classroom, the educational purpose of its use should be grounded in learning theories in order for the technology to be effectively designed and used. Also, the most critical challenges that researchers must overcome is effective integration of gamified AR in the classroom to reduce cognitive load, engage students beyond the novelty effect and increase transfer of knowledge (Appleton, 2005; Clark & Mayer, 2003; Paas et al., 2005). Many theories have been developed to address technology integration while focusing on the principles of learning and the effects of technology on cognition. In particular, the Cognitive Theory of Multimedia Learning (CTML) addresses how information should be presented to account for students' limited working memory. CTML focuses on the mental processes of students so they can actively process information presented without experiencing cognitive load (Mayer, 1997). This research leverage CTML to guide instructional design of gamified learning AR (GLAR) applications while evaluating the cognitive effects GLAR on students. 3.2

Purpose of the Study The goal **of this study is to** reveal **how the use of** gamified AR effects **the**

cognitive system of students with and without prior knowledge of the learning content. An additional aim is to generate recommendations for using game elements to design gamified AR activities to account for cognitive load. Prior knowledge is an important factor in the ability for students to generate inference and create new knowledge (Fincher-Kiefer, 1992; O'Reilly & McNamara, 2007), organize new knowledge to form mental representations

(Rawson & Kintsch, 2004), and generally improves comprehension (Lipson, 1982; Shapiro, 2004).

CTML examines the process limitations of students' working memory and their ability to handle multiple bits of information simultaneously (Mayer & Chandler, 2001). CTML assumes that prior knowledge is necessary to overcome these limitations and enrich students' mental representation of information being presented (Mayer, 2005). Although

a positive relationship between prior knowledge and learning has been supported in the educational psychology literature

(Shapiro, 2004; Thompson & Zomboanga, 2003), further research on the effects of prior knowledge when using technology is needed to bring more clarity on how it influences students' cognitive load. Therefore, a goal

of this study is to investigate the effects of prior knowledge on students' cognitive load. In

addition, we will examine which game elements students perceive as helpful and distracting during a gamified AR activity. For this study, focus groups were utilized as an approach to gather information from students on how to improve the development of GLAR applications and how the use of game elements may minimize or maximize cognitive load. The effects of prior knowledge on knowledge creation was examined using pre-/post- assessments and cognitive load surveys. 3.3 Related Work 3.3.1 Prior Knowledge Bloom (1976) suggested that one-half of the variance on relevant cognitive achievements measures can be explained by "those prerequisite types of knowledge, skills, and competencies which are essential to the learning of a particular new task or set of tasks." According to Dochy 61 (2002),

prior knowledge generally explains between 30 and 60 percent of the variance in study results

and overrules all other variables. Researchers such as Newman and Schwager (1995) investigated how students with different levels of prior knowledge seek help during problem solving activities in math while Duff (2004) examined how prior knowledge, among other variables, affected how first-year accounting and business students approached learning. Lee, Pliskin, and Kahn (1994) examined the relationship between performance and the students' prior knowledge in a computer science course. The results of these studies indicate significant correlation of prior knowledge on learning. These studies found that students with prior knowledge had a significantly higher performance than students without prior knowledge. These studies strongly suggest that prior knowledge is an important factor which plays a vital a role in facilitating students' cognitive achievements.

Piaget's (1985) **theory of cognitive development** suggests that **prior knowledge** is the key **to**

learning development. Mayer expressed the importance of prior knowledge on processing information when using educational technology. His research suggests that using multiple channels to produce mental representations allows students to integrate the information presented with prior knowledge to construct new knowledge (Mayer, 2005). Research conducted by Contero, suggests that AR supported by CTML can be used in the learning environment to reduce gaps in a student's knowledge and significantly account for cognitive load (Contero & Alcaniz, 2010). 3.3.2 Why a student's perceptive approach? ecoCampus was an educational-based AR simulation game that was created

to improve sustainability education of engineering students through the development and

exploration (Ayer, Messener & Anumba, 2013). Situating ecoCampus allowed first-year engineering students to "create a variety of hypothetical design concepts, visualize those designs in the context of an 62 existing space, and receive performance feedback about those concepts related to sustainability and other key building metrics." Five weeks after the implementation of ecoCampus in the classroom, students participated in focus groups. The small focus groups offered students the opportunity to share their overall perceptions of the AR activity and have an open discussion with their peers on how they felt about ecoCampus. Feedback from the focus group sessions helped researchers understand how instructional principles can be used to build other AR applications similar to ecoCampus. Researchers concluded that gathering students' perspective allowed them to understand how students interacted with the application, and to gain insight on whether students felt ecoCampus provided them with enough information to make effective decisions and increased their interest in the building design process. Ayer, et al. demonstrated that a student's perceptive approach offered students a less- structured method to provide their thoughts on how AR learning activities can increase their knowledge of design content and impact their learning environment. Although focus groups were not anonymous, students felt comfortable giving their feedback in sessions because of the unstructured format and support of their peers. Many researchers believe that gathering students' perspectives through focus groups provides researchers with rich information because students are able to openly discuss their experiences as well as expand and disagree with other students' ideas and opinions (Morgan, 1996). 3.4 Experimental Testbed: Celestial Blast. A Gamified Learning AR application For this research, a custom GLAR application was built to serve as a key testbed component. Unlike other AR applications that require participants to wear head-mounted displays or use spatial projectors, this study developed a handheld tablet-based AR application. Celestial Blast is an interactive AR game developed to reinforce the mathematical concept of angles to 63 participants. The goal of Celestial Blast is for participants to identify and classify incoming asteroids' angle of attack as right, obtuse, acute or straight. Once identified and classified, participants must use a turret to measure and then destroy asteroids. Celestial Blast was developed in the COGENT Lab

at Virginia Polytechnic Institute and State University by five undergraduate **Computer Science**

students using Unity and the AR ToolKit library. To deploy Celestial Blast requires an Android tablet to render the virtual information and a printed AR marker to position the virtual information into the real-world scene. An AR marker is a printed pattern or picture that contains a pre-programmed visual pattern that the tablet camera can recognize and use to determine the position and pose of AR content. The marker used in Celestial Blast was movable, allowing the participants to view the virtual objects from different angles (Hubbard, 2009). For this gamified AR activity, the marker stood up vertically in front of the tablet so it was within the tablet camera's field of view at all times (see figure 3). Figure 3: Experimental Setting The learning content used to inform the design of Celestial Blast came from the Virginia Department of Education 5th grade curriculum. The GLAR application addressed two specific learning aims adopted from Virginia Public Schools' Standard of Learning. Aim one states that participants should be able to identify and classify angles as right, obtuse, acute or straight. The second aim states that participants should be able to measure right, obtuse, acute and straight angles. The application was designed by leveraging principles of gamification and CTML. Celestial Blast is composed of six gamification elements: rewards, freedom to fail, progress, feedback, score, and levels. Each gamification element is integrated into the application design to help participants interact with virtual objects and focus their attention on understanding the learning content. Based on CTML design principles, the application utilizes dual channels of modality to allow for visual and auditory processing. Also, auditory and visual information is presented simultaneously to reduce participants' cognitive load when interacting with the application. Celestial Blast, as shown in figure 4, was designed around the theme that there are friendly, peaceful and super tiny "ploofs" that need participants' help. Participants have to save the ploofs' town (shown in green, below the turret in figure 4) from being destroyed by incoming asteroids. The asteroids and ploofs' town are shown virtually using AR and can only be seen through the Android tablet. Each asteroid approaches the town from a different angle and is labeled with a number denoting incoming angle of attack in degrees. The town is rendered on the marker in one of three color coded states. When the town is green, it is in a healthy, strong condition; when the town is yellow it indicates that the town has been hit by two asteroids; and when the town is red, it is very close to destruction, and a single additional asteroid hit will destroy the town. On top of the town, a turret is rendered that participants manipulate in order to destroy incoming asteroids. The bottom of the screen displays the health bar, the amount of ammunition remaining, angle classification and score. The heath bar allows participants to track the health of the ploofs' town, ammo remaining tracks how much ammunition is left, and angle classification is correlated to the position of the turret. Participants must pay attention to the text that correlates to the turret angle as well. For example, it the turret is at twelve degrees the classification will indicate acute. To play the game, participants position their finger on the tablet surface to drag the turret along an invisible protractor arc. Once the turret position and the angle of the incoming asteroid match, participants release their finger to fire the laser and destroy the asteroid. The more accurate the laser fire, the more points participants earn. Also, the longer participant's keep the town safe, the more points and ammo they will earn. Accurately matching the angles of the incoming asteroids to the angle of the turret will also conserve ammo. When participants run out of ammo, they can refill by correctly answering questions about angles. Questions were adapted from Virginia Standards of Learning sample and practice questions on the topic. If a question is answered incorrectly, participants can no longer protect the town and the game is quickly over. Once the game has ended, participants can keep replaying during the remaining allotted activity time to attempt to set a new personal or classroom high score. Figure 4: Celestial Blast Interface 3.5 Methodology This section outlines the

research questions, describes **the research design and** includes **the** approaches **used to** address **the**

research questions. It also outlines characteristics of the participants, research setting, instrumentation for data collection, research limitations and assumptions. 3.5.1

Research Questions and Hypotheses The **study** addresses **the following research questions:** Research Question 1: **Does**

prior exposure to learning content have an actual and perceived effect on GLAR performance? Hypothesis (H1): There are significant actual difference in GLAR performance between students with and without exposure to learning content Research Question 2: Does prior exposure to learning content effect cognitive load when using GLAR application "Celestial Blast"? 67 Hypothesis (H2): There are

significant difference in cognitive load between students **with and without**

exposure to learning content when using GLAR application "Celestial Blast". Research Question 3: Will engagement with GLAR improve content-based

learning gains for **students with and without prior exposure to**

learning content? Hypothesis (H3): Engagement with GLAR improves content-based learning gains for both students with and without prior exposure. Hypothesis (H4): There is no significant difference between content-based learning gains for students with and without prior exposure. 3.5.2 Research

Design This study used a mixed method, **between-subjects** two-group **experimental design**

with purposive sampling.

Both quantitative and qualitative data were used to examine **the** perception **of**

participants with respect to cognitive load, content-based learning gains, user experience and usefulness of gamification elements. Participants were broken in two groups: experienced participants and novice participants. Since purposive sampling was used to gather participants, the groups were naturally occurring and not randomly assigned. 3.5.2.1 Independent and Dependent Variables This study has one independent variable which was prior knowledge, with two levels, novice and experienced. Participants were considered novice if they did not have prior exposure to the learning content which was confirmed by their school teacher. We considered participants experienced if they had prior exposure to the learning content during the 2016 – 2017 academic year. The dependent variables of the study were results on pre-/post- assessment, learning gains, average game score, highest game score, number of plays and cognitive load scores. The dependent measures were collected through self-reported cognitive load surveys (NASA TLX), pre-/post- assessments and GLAR game metrics. ? Pre-/Post- assessment results: pre-assessment determined the participants' level of understating of learning content before exposure to Celestial Blast. The results ranged from 0 (lowest/no questions answered correctly) to 10 (highest/all questions answered correctly). The post-assessment determined the participants' level of understanding of the learning content after exposure to Celestial Blast. The results ranged from 0 (lowest/no questions answered correctly) to 10 (highest/all questions answered correctly). ? Learning gains: these gains are calculated as the differences between pre- and post- assessment results, and ranged from -3 (lowest/worst) to 6 (highest/best). ? GLAR game metrics: average score across all games played, highest score achieved, and number of game plays. Students had the freedom to fail and replay Celestial Blast multiple times within the allotted time, the number of game plays can ranged from 1 (best) to infinite (worst). ? Cognitive load scores: average workload from NASA TLX survey ranged from 0 (lowest workload) to 1 (highest workload). 3.5.2.2 Focus Groups The study also utilized focus groups to capture participants' perceptions on how the gamified AR activity affected them cognitively, it also helped researchers understand how participants perceived the application and identify what gamification elements kept them focused on the learning content. 69 3.5.3 Participants Understanding the target population is crucial component of

establishing a valid experiment with reliable data and conclusion **(Creswell,**

2009). Most of the existing literature investigating AR as an educational tool has included participants in higher education, e.g., community college and four-year universities (Appleton, 2005). To expand on this body of literature, the target population for this study was fifth grade students from Title I schools in Virginia Public School system. Title I is a funding program provide by the U.S. Department of Education to "assist low income and at-risk students who are struggling academically to obtain a high-quality education and reach, at minimum, proficiency on challenging state academic achievement standards and assessments" (U.S. Department of Education, 2011). Title I funding was created out of the No Child Left Behind Act of 2002 with hopes of closing the achievement gap between students in low socioeconomic and high-income communities. This study engaged 35 participants from four different elementary schools in the Southwest region of Virginia. Each school had fifth grade classroom sizes between 9 to 16 students. All participants were educated through grade four and passed Virginia SOLs in order to move onto the fifth grade. We gained access to participants through Virginia Tech's Kindergarten-to-College (K2C) program. This program was developed to inspire potential first-generation college students to pursue degrees in higher education. K2C brings fifth grade students from Title I schools in Virginia to Virginia Tech's Blacksburg campus to participate in STEM activities and gain first-hand exposure to cutting edge research and technology.

There was a total of four schools **who participated in the study,**

two schools provided access to novice participants and the other two schools provided access to experienced participants. Individual schools visited Virginia Tech Blacksburg campus on separate occasions over the course of one month. 70 The experienced group contained 17 participants, and novice group contained 18 participants. It was assumed that both groups had a basic understanding of a protractor which allowed navigation through the GLAR application without being completely confused. 3.5.4 Research Setting This research occurred

during the spring **semester of the 2016-2017** Virginia Tech **academic school year. The**

study was conducted on the Virginia Tech Blacksburg campus in a controlled classroom to alleviate

potential distractions such as off-task participants, **hallway noise or**

interruptions, and control for lighting. Natural outdoor lighting can cause glare on the tablets and prevent tablet cameras from reliably detecting AR markers. Inside the classroom, participants sat in groups of six. However, each participant had their own Android tablet and marker. At the start of the study, the marker was placed directly in front of participants but they could move it at any time per their preference and desire. 3.5.5 Instrumentations 3.5.5.1 Pre-/Post- Assessments

In order to evaluate participants' **prior knowledge** on angles, **participants were given a pre-**

assessment that included questions derived from previous SOL assessments. To evaluate whether or not new knowledge was created after interacting with Celestial Blast, a post- assessment was also administered. Both the pre- and post- assessment had ten questions that required participants to demonstrate their ability to identify, classify and measure angles. Although the pre- and post- assessments were separate, both used multiple choice format for questions to mimic the style of actual SOL tests. The SOL questions used were state-approved in accordance with Virginia Department of Education guidelines and meet state educational standards. The assessments were deemed reliable and an effective assessment instruments by state administrators. 3.5.5.2

NASA Task Load Index (TLX) NASA TLX **(Hart** and **Staveland, 1988)** was **used to assess** a direct, **subjective**

measurement of participants' perceived cognitive load during the gamified AR activity. The TLX contains multidimensional scales assessing

six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration.

Table 2 provides a summary description for each dimension as well as the endpoints used in their measuring scale (Valdehita, Ramiro, Garcia, Puente, 2004).

Each dimension operates on a 21-point ordinal Likert scale (1 = very low and 21 = very high).

Through extensive validation studies, Hart and Staveland (as well as others) have established NASA TLX as a valid and effective measure of self-reported cognitive load. Additional researchers concluded that NASA TLX's six dimensions accounted for significant variance in cognitive load (Bortolussi, Kantowitz & Hart, 1985; Byers, Bittner & Hill, 1989; Hart & Staveland, 1988; Haworth, Bivens & Shively, 1986; Vidulich & Tsang, 1986). The NASA TLX was not altered from its original state and when analyzing data from the survey, researchers choose to use the raw scores instead of weighted scores. The use of raw scores has been recommended when broad segments of work are examined; weighted scores are recommended when specific work tasks are examined or when different work segments are compared (Hart, 1992). It was determined that elementary school

students are capable of self- reporting their perceived mental effort using an ordinal scale

such as NASA TLX therefore we expect NASA TLX to be a valid instrument for this age demographic (Paas & van Merriënboer, 1993; Brown, 1999; Paas et al., 2008; Gopher & Braune, 1984). Also, according to Flesch-Kincaid 72 Grade Level Readability formula and the Automated Readability Index the understandability and reading level of the NASA TLX corresponds to a fifth grade level. Table 2: NASA TLX Rating Scale 3.5.5.3 Focus Group This research used focus groups to gather information from the participants on the overall usefulness of the GLAR application and whether participants' cognitive load increased or decreased while interacting with GLAR. Krueger and Casey (2000) defined focus groups as: "a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, nonthreatening environment. ... The discussion is relaxed, comfortable, and often enjoyable for participants as they share their ideas and perceptions. Group members influence each other by responding to ideas and comments in the discussion." Focus groups allow a small group of six to ten participants to have an open discussion led by a moderator (Patton, 2005). The role of the moderator is to ask questions when discussion on a particular topic ends and to redirect participants when they began to get off topic. The goal is to generate the maximum amount of different ideas and opinions from as many different participants in the allotted time. Participants should feel comfortable sharing their views without constraints. Focus groups are structured around a set of predetermined questions but allow participants' discussion to be unstructured. However, follow-up questions are used as needed to clarify and expound on participants' answers. For this work, focus groups elicited participants' perspectives that aim to help researchers evaluate participants' perceived cognitive load and the existing GLAR application, as well as garner feedback on how to improve future GLAR applications to minimize cognitive load. The focus groups allowed participants the opportunity to express their thoughts in loosely-structured setting and interact with other participants during the discussion. For this research, focus group discussions were audio recorded and the moderator took extensive notes to help with the transcription process. 3.5.6 Data Collection Procedures This study employed a five-step process: 1. Introduction to Research Team and Celestial Blast Instructions (~10 min) 2. Pre- Assessment (~10 min) 3. Interact with Celestial Blast (~30 min) 4. Post- Assessment (~10 min) 5. Focus Group Interviews (~20 min) First, participants were introduced to the primary researcher and designers of the GLAR application. The research team gave a presentation on game instructions and showed an example on how to use Celestial Blast. This presentation occurred during the first 10 minutes of the gamified AR activity. Next, participants completed a pre- assessment survey to evaluate their prior knowledge by answering SOL questions on a specific mathematical area (i.e., angles). Researchers gave verbal instructions and answered questions as needed. Following the pre- assessment, participants interacted with Celestial Blast individually for thirty minutes. During game play, researchers walked around to assist participants if they had any questions on the learning content or AR interface (see figure 5). For example, if a participant was having trouble seeing the graphics, the researcher instructed the participant to manipulate or move the AR marker to increase or decrease their field of view or rotate the graphic. Figure 5: Researchers assisting participants After the learning activity, all participants completed the post- assessment to evaluate if there were any learning gains. Following the post-assessment, participants completed the NASA TLX, which allowed them to self-report their cognitive load during the gamified AR activity. Once again, the researchers gave verbal instructions and answered questions as needed. During the final step, participants were placed in groups of 5 and 6 to participate in focus groups. These groups were homogenous with respect to prior knowledge since only one school participated in the study at a time. They sat in a circle and two researchers joined each group. One researcher served as a note taker and observer while the other researcher served as the moderator. The moderator asked participants questions and facilitated the conversation. If they noticed one of the participants was not engaging in the conversation, the researcher purposely directed a question to that participant. This was an important strategy to ensure focus group data included feedback from all participants. 3.6 Results 3.6.1 Research Question 1 Does prior exposure to learning content have an actual and perceived effect on GLAR performance? 3.6.1.1 Descriptive Statistics Actual GLAR performance was analyzed using three game metrics of Celestial Blast: (1) average game score, (2) highest game score, and, (3) number of game plays. Descriptive statistics for these three game metrics by prior exposure can be found in tables 6, 7, and 8. The data shows novice students had a median average game score of 1045.86, with minimum and maximum average game scores of 516.76 and 3044.25 respectively; median highest game score was 2705 respectively, with minimum and maximum highest game scores of 1420 and 6520; and median number of plays was 7, with minimum and maximum number of plays of 4 and 17 respectively. Experienced students had a median average game score of 1279.72, with minimum and maximum average game scores of 349.615 and 7025 respectively; median highest game score was 3447.5 respectively, with minimum and maximum highest game score of 1170 and 9174; and median number of plays was 7, with minimum and maximum number of plays of 1 and 13 respectively. Table 3: Descriptive Data for Number of Game Plays by Prior Exposure M SD n Min Max 25 Percentile 50 75 Experienced 6.389 3.664 Novice 8.647 3.904 17 18 4 17 1 13 6 3 7 7 12 9 Note. Lower number of game plays resulted in improved GLAR performance Table 4: Descriptive Data for Highest Game Score by Prior Exposure

M SD n Min Max 25 Percentile 50 75 Experienced 4166.78 2544.167 18 Novice 3138.52 1555.79 17 1420 1170 6520 9174 1675 2705 4075 2091.25 3447.5 6809.75 Table 5: Descriptive Data for Average Game Score by Prior Exposure M SD n Min Max 25 Percentile 50 75 Experienced 2117.88 1886.14 Novice 1340.98 742.49 17 18 516.76 3044.25 807.78 1045.86 1679.29 349.62 7025 618.06 1279.72 3342.65 Figure 6. Average Game Score by Prior Exposure Figure 7. Highest Game Score by Prior Exposure Figure 8. Number of Game Plays by Prior Exposure 3.6.1.2 Hypothesis Testing Hypothesis (H1): There are significant actual difference in GLAR performance between students with and without exposure to learning content. Kruskal-Wallis tests were conducted on each of these measures to evaluate differences

between students with, and without, prior exposure to the

learning content. All three tests found no significant differences (table 6): (1) average game score, Z = 0.545, p = 0.586, (2) highest game score, Z = 0.908, p = 0.364, and, (3) number of game plays, Z = 1.428, p = 0.153; therefore, we can reject hypothesis 1 and assume prior exposure to learning content does not have an actual effect on GLAR performance. The

effect size was also **calculated to** better understand **the magnitude of the difference between groups**

(Sullivan & Richard, 2012). Using the Z score obtained from Kruskal-Wallis analyses, the Wilcoxon effect size was calculated using: r = Z

$\sqrt{n}$ **, where n is the total number of** samples. **The** Wilcoxon effect **size**

is considered large when it is more than 0.5, medium when it is between 0.3 and 0.5, and small when it is less than 0.3 (Grissom & Kim, 2012). Therefore, the effect size for average game scores, highest game score and number of plays are deemed small. Table 6. GLAR performance Kruskal-Wallis Test Results n Chi-square df p-Value Z-Value R Average Game Score 35 0.3148 1 0.586 0.545 0.092 Highest Game Score 35 0.854 1 0.364 0.908 0.153 Number of Plays 35 2.088 1 0.153 1.428 0.241 3.6.1.3 Qualitative Coding Process of

Focus Group Data Once **the focus group** interviews **were** completed, the **recorded** conversations were **transcribed**

and analyzed using a three-step coding process. Throughout the coding process, we noted our thoughts in analytical memos to help make comparisons amongst the categories, codes and clusters and ultimate derive key themes. In open coding, categories evolved from the analysis of the transcripts by grouping words and phrases together. The outcome of the open coding process was the emergence of 25 categories. Some of the emerging categories were frustrations, engagement, functionality, collaborations, novelty and gamification elements. During this step, memos allowed us to determine how to begin to explain how GLAR impacted student performance. Next, axial coding helped aggregate the categories to identify codes that describes relationships amongst categories. Codes were grouped together by category and subcategory to 82 make sense of the focus group data. This was an iterative process, in which we constructed, deconstructed, and reconstructed categories and sub-categories to identify13 key codes that were effective at explaining and making sense of the data. Lastly in selective coding, we developed meaningful clusters that connected together related axial codes that explains how students perceived their GLAR performance. The clusters were compared and contrasted with each other to investigate interconnections between novice and experience students. These clusters were subsequently developed into the five key themes. 3.6.1.4 Qualitative Findings of GLAR performance by Prior Exposure The qualitative coding of the focus group transcripts uncovered five key themes. First, the use of gamification elements

had a positive effect on game **performance** for both **students with** and without **prior**

exposure to the learning content. Second, understanding of learning content impacted students game performance. Third, students reported that their sense of engagement was beneficial to their GLAR performance. Fourth, students reported feeling stressed and frustrated with the game functionality and design. Fifth, both students with and without prior exposure to the learning content reported that PLearning was important for successful GLAR performance. PLearning was a term defined by the participant as play and learning simultaneously. The five key themes from the qualitative data further explains the quantitative results to create a richer description of the overall findings for research question one. Below we outline the key themes by participant classification and identify significant statements from the raw focus group transcripts (see table 7). Table 7. Key Themes from Qualitative Coding Themes Novice Students' Quotes Experienced Students' Quotes Use of Gamification Elements "The information at the bottom of the screen in the progress bar helped me be successful at playing the game." "This game was addictive because I kept wanting to get a high score. " "I did not like the theme of the game because it was not realistic and I wanted it to be related to sports." "I was comfortable playing the game because the progress bar at the bottom helped me." "I like seeing the explosions feedback because I know I was playing the game right." "If I looked at my score during the game I would have been stressed to keep getting a higher score; therefore, I waited until the end of the game to look at my score because I wanted to focus on the asteroids." "Being able to keep playing the game after dying was helpful and motivated me to keep getting a better score." "I like clearing the levels because I was doing something rewarding like saving the ploofs." "Being able to see my score throughout the game was helpful and the best part." "The +30 and +5 feedback was helpful to know how I was doing." Understanding of Learning Content "It was hard for me to make connections between the angles and incoming asteroids… I wish I would have known more about angles before playing the game." "Since I got my angles down I wasn't stressed because if it said to shoot an acute angle I knew what an acute angle was." "Seeing the number on the asteroids helped me to make connections on what the angle classification was." "I had to put in a lot of effort because the game requires a lot of concentration and focus especially when they started coming faster." "The AR helped me to visualize the angle and made it easier for me to identify and classify the angles." "I died a few times because I thought 90 was acute but I was taught acute was less than 90 degrees but from the game I learned 90 is a right angle." "My performance was bad because I didn't know anything about angles." "The game was easy because I understand how to identify and classify angles." "Since I didn't know the angles

I had to think harder to remember what the classification was and it made me a little stressed." "I was able to develop and reinforce my angle knowledge quickly by playing the game." Benefits of Engagement "I was not stressed playing the game because it kept me engaged." "The game was engaging and normally I get annoyed after playing a game but not with this one." "The game was engaging, and I was upset I didn't get to finish." "I wanted to keep playing the game because it was addicting." "I would give this game a 9 out of 10 on the engagement scale because playing in real world was better than paper." "I give this game an engagement score of 8 because it was challenging and forced me to act and think quickly to shoot the asteroids." "The game was entertaining and additive because I was so engaged in shooting the asteroids." "The game could help everyone because it is engaging." "The game was engaging and educational because of the story of protecting the ploofs." "The AR made the game more alive and engaging." Game Functionality and Design "Seeing the angles in my real world was helpful in my game performance verses learning with paper how we normally see it." "Having the angle number and classification in the sphere at the bottom and having to match it to the asteroid I wanted to destroy helped with my performance." "I like having both the sound and graphics at the same time…. The numbers on the asteroids helped me play the game better." "Sometimes when I got to a higher level all the asteroids were mentally demanding." "The game made me think a lot because I had to see if I would hit "I'm grateful for the questions to get more ammo because it the asteroid and had to think about the angle at the same time." stopped the time and gave me more time to think." "I was stressed a little bit because it was a lot of asteroids at one time and it was hard for me to focus." "I think the game could use more sounds and graphics." "Answering the question when I had one ammunition left was the best featured of the game that really helped me." "I like the visuals and the sound because it helped me learn and pay attention." PLearning (Playing and Learning Simultaneously) "PLearning is better than learning because it is a fun way to learn boring stuff." "I like that I was learning but still having fun and that was a rare thing." "Playing the game helped me to learn about angles while having fun." "This game is the best game ever because it's a teaching game and fun." "The fact that you guys were able to incorporate learning math into a game that was fun was great." "Playing the game helped me on the post-assessment." "Playing with the turret in the game reminded me of moving along a protractor and it was helpful." "By moving the turret I felt like I was moving a protractor which was fun and helpful. " "I wish the game had multi player mode so I could play and learn together with my friends." "I don't think I did well when playing the game because I don't like to play games and learn…. I would rather just play games for fun without learning." 3.6.2 Research Question 2 Does prior exposure to learning content effect cognitive load when using the GLAR application "Celestial Blast"? 3.6.2.1 Descriptive Statistics Cognitive load was assessed using the dependent measure of average workload which is the unweighted NASA TLX results. Descriptive statistics for average workload across prior exposure is summarized in table 10. The data shows novice students had a median average workload of 0.45, with minimum and maximum average workload of 0.11 and 0.83 respectively and experienced students had a median average workload of 0.45, with minimum and maximum average workload of 0.16 and 0.76 respectively. Figure 7. Comparing Average Workload by Prior Exposure Table 8. Descriptive Data for Average Workload by Prior Exposure Percentile M SD n Min Max 25 50 75 Novice 0.448 0.140 17 0.117 0.758 0.367

0.45 0.529 Experienced 0.484 0.173 18 0.167 0.833 0.381 0.45 0.594 3.6.2.2 Hypothesis Testing Hypothesis (H2): There are significant differences in cognitive load between students with and without exposure to learning content when using the GLAR application “Celestial Blast”.

A Kruskal-Wallis test was conducted to evaluate differences between

students with and without prior exposure to the learning content on median change in average workload. The test showed no significant differences in average workload, Z = 0.380, p = 0.704, between students with and without exposure to the learning content (table 8); therefore, we can reject the hypothesis. The effect size for cognitive load was 0.064. Table 9. Cognitive Load Kruskal-Wallis Test Result n Chi-square df p-Value Z-Value r Average Workload 35 0.157 1 0.704 0.380 0.064 3.6.3 Research Question 3 Will engagement with GLAR improve content-based

learning gains for **students with and without prior exposure to**

learning content? 3.6.3.1 Descriptive Statistics Content-based learning gains were assessed using the dependent measures of (1) pre- assessment results and (2) post-assessment results. Descriptive statistics for FID and FD students across pre- and post- assessments are summarized in tables 12 and 13. The data shows novice students had a median pre-assessment score of 4, with minimum and maximum pre-assessment scores of 2 and 7 respectively; and median post-assessment score of 7, with minimum and maximum post-assessment scores of 2 and 8 respectively. Experienced students had a median pre- assessment score of 9, with minimum and maximum pre-assessment scores of 3 and 10 respectively; and median post-assessment score of 9, with minimum and maximum post- assessment scores of 7 and 10 respectively. Figure 8. Comparing Pre- and Post-Assessment by Prior Exposure Table 10. Descriptive Data for Pre-Assessment by Prior Exposure M SD n Min Max 25 Percentile 50 75 Experienced 8.056 1.862 Novice 4.059 1.478 17 18 2 7 3 10 3 7 4 9 5 9 Note. The maximum possible score on pre-assessment was 10. Table 11. Descriptive Data for Post-Assessment by Prior Exposure Percentile M SD n Min Max 25 50 75 Novice 5.412 1.698 17 2 8 4.5 6 6.5 Experienced 9.056 0.938 18 7 10 8 9 10 Note. The maximum possible score on post-assessment was 10. 3.6.3.2 Hypothesis Testing Hypothesis (H3): Engagement with GLAR improves content-based learning gains for both students with and without prior exposure. Two Wilcoxon Signed-ranked tests were

conducted to evaluate **if there were significant differences between pre- and post-** assessments **for** both **students**

with and without prior exposure to learning content. For novice students, the Wilcoxon Signed-rank test indicated significant differences between pre- (Mdn = 4) and post- (Mdn = 6) assessment scores, Z = -3.418, p < 0.0001. The effect size of the pre- and post-assessment for novice students was r = 0.829. For experienced students, the Wilcoxon Signed-rank test did not find significant differences between pre- (Mdn = 9) and post- (Mdn = 9) assessment scores, Z = 0.805, p = 0.421. The effect size was r=0.189. Therefore, we reject the hypothesis and assume that engagement with Celestial Blast did not improve the content-based learning gains for both students with and without prior exposure to the learning content. Table 12. Novice Students' Wilcoxon Signed-rank Test Results Novice Post-Assessment – Novice Pre-Assessment Z -3.418 p < 0.0001* Table 13. Experienced Students' Wilcoxon Signed-rank Test Results Experienced Post-Assessment – Experienced Pre-Assessment Z 0.805 p 0.421 Hypothesis (H4): There are significant differences between content-based learning gains for students with and without prior exposure. Learning gains were quantified using a

difference score that **was calculated as the difference between the** pre-assessment **and** post-assessment **scores.** Descriptive statistics for **difference score**

between students with and without prior exposure is summarized in table 16. The data shows novice students had a median difference score of 1, with

minimum and maximum difference scores of -1 **and** 4 **respectively** and experienced students **had a** median **difference score of**

1, with

minimum and maximum difference scores of -2 and 6 **respectively.**

Figure 9. Comparing Assessment Score Differences by Prior Exposure Table 14. Descriptive Data for Assessment of Learning Gains by Prior Exposure Percentile M SD n Min Max 25 50 75 Novice 1.353 1.538 17 -1 4 0 1 2.5 Experienced 1 2.058 18 -2 6 -1 1 2.25 A Kruskal-Wallis Test was conducted to evaluate hypothesis 4 and determine if there were differences between students with and without prior exposure to learning content on median change in content-based learning gains. The test was not significant, Z = -1.219, p = 0.223; therefore, we

reject the hypothesis and assume **that there** are **no significant** differences **between**

content-based

learning gains for **students with and without prior exposure. The**

effect size of the learning gains was r = .136. Table 15. Assessment of Learning Gains Kruskal-Wallis Test Result n Chi-square df p-Value Z-Value r Learning Gains 35 0.675 1 0.223 -1.219 0.136 3.7

Discussion The goal of this study is **to investigate the effects of** prior knowledge **on** content-based **learning**

gains, students' cognitive load and GLAR performance. The key, significant

findings from this study suggest, (1) **there were** no **differences between** novice **and**

experienced students' cognitive load, and, (2) novice students' content-based learning gains can be improved through interaction with GLAR. 3.7.1 GLAR performance (Research question 1) If students have strong prior knowledge of a topic that is related to the learning activity, then the inclusion of GLAR may increase their performance during the activity (Oulasvirta & Saarilouma, 2004). In this study, experienced students tended to have better highest and average game scores as compared to novice students (which bolster the claims by Oulasvirta and Saarilouma). While

there were no statistically significant differences between the two **groups** for each **dependent measure of** GLAR **performance,**

there were identifiable differences at p=0.092 for average game score. Hoffman (2010) noted that the use of a different model or increasing the p- value of the test could provide statistically significant differences between novice and experienced students GLAR performance. Recent research indicates that

p-values between 0.05 and 0.1 can be **considered**

“marginally significant”. We believe these “marginally significant” differences could be explained by the qualitative data. Most of the qualitative findings between students with and without prior exposure to learning content were similar. However, their opinions did differ amongst some of the five key themes. While each key theme is discussed separately below, it is important to note that we cannot conclude which key theme or interaction of themes had the greatest effect on GLAR performance. Use of Gamification Elements. According to Kapp, gamification elements are considered important constructs that intrinsically motivate students and improve performance (Kapp, 2012). Experienced students felt that gamification elements such as high score, freedom to fail, and levels gave them the additional motivation to perform. Participant eleven shared in the focus group, “Being able to keep playing the game after dying was helpful and motivated me to keep playing to get a high score.” And a commonly noted comment across the experienced group indicated that, “The game was addictive because I wanted a high score.” However, for novice students, gamification elements such as narrative and high score were distracting and possibly hindered their GLAR performance. According to participant 34, “If I looked at my score during the game, I would have been stressed to keep getting a higher score; therefore, I waited until the end of the game to look at my score because I wanted to focus on the asteroids.” The inclusion of gamification elements may be overwhelming to students who are unfamiliar with the learning content; therefore, when using gamification elements, instructional GLAR designers should consider prior exposure to learning content (Hanus & Fox, 2015; Landers, 2014). Understanding of Learning Content. Understanding learning content is key to students’ performance with GLAR. Experience students complained about being frustrated with the learning 94 material being presented in Celestial Blast. This qualitative finding was not surprising because experienced students were not building new knowledge, so it is expected that they would experience some frustration due to the expertise reversal effect. Indeed, participant 34 mentions “I was annoyed and didn’t enjoy the game until the asteroids started coming faster and made me think harder.” However, both novice and experienced students reported improved understanding of learning content after using Celestial Blast. Participant 14 mentioned, “I was able to develop and reinforce my angle knowledge quickly by playing the game.” Likewise, participant 22 said, “On the pre-assessment I did badly and I performed bad because I didn't know anything about angles. But I think I got an 8 out of 10 on the post-assessment." Both experienced and novice students found the GLAR learning activity to be useful and help them better understand the learning content being presented. Also it is important to mention that experienced students were overconfident in their Celestial Blast performance. For example, experienced students reported that "the game was easy because I (already) understand how to identify and classify angles," and "since I got my angles down I wasn't stressed because if it said to shoot an acute angle I knew what an acute angle was." However, their actual GLAR average and highest game scores were not significantly different as compared to novice students. Benefits of Engagement. Jenson (2009) stressed the importance of engaged learning, which activates students to participate emotionally, cognitively, and behaviorally, which in turn improves performance. Both novice and experienced students noted the importance of engagement, as evident by one of the novice students' comments that, "I would give this game a 9 out of 10 on the engagement scale because playing in the real world was better than using paper to learn." Comments similar to this were echoed for novice and experienced students alike. Within the context of Celestial Blast, gamification and AR was successful at increasing engagement to participate in higher order cognitive processing. Experienced participant 13 reported, "I give this game an engagement score of 8 because it was challenging and forced me to act and think quickly to shoot the asteroids." Game Functionally and Design. There were some frustrations expressed about game functionality and overall design. Combining elements of AR, gamification and CTML to learning content can compound some frustrations, turning what was intended to be a fun and interactive experience into the opposite. Although students like that GLAR was a different approach to traditional in-classroom learning methods, some reported being stressed and overwhelmed which hindered their performance. Some of the comments included: "Sometimes when I got to the higher level all the asteroids were mentally demanding," and, "I was stressed because it was a lot of asteroids at one time and it was hard for me to focus," and, "The game was lagging which caused some frustration and made me die a lot." Thus, it appears that game functionality and design impacted both novice and experienced student Celestial Blast performance. Therefore, further research is needed to examine each component of Celestial Blast's functionality and user interface design. According to Dicheva et al. (2015), student responses are critically important to good testing processes when designing any kind of gamified technology. Therefore, by identifying which functionality and elements cause dissatisfaction, instructional designers can avoid these elements and instead embrace improved designs when designing future GLAR applications. PLearning (Playing and Learning Simultaneously). Lastly, plearning (play+learning) was a term that emerged from the focus group interviews. When discussing playing and learning simultaneously, both novice and experienced students made such comments as, "PLearning is better than learning because it is a fun way to learn boring stuff," and, "I really felt like I was learning and that is a rare thing while playing a game," and, "I liked that I was learning but still 96 having fun at the same time." Similar sentiments were echoed during the focus group interviews. These comments present evidence that plearning

had a positive effect on GLAR game **performance.** 3.7 **.2 Cognitive load** (Research **question**

2) Our results suggest that GLAR designers and developers should account for prior exposure, otherwise a one size fits all approach could have a negative impact on experienced students' cognitive load. According to Mayer, both the complexity of learning content and prior exposure to that learning content can effect students' cognitive load (Mayer, 2003).

There were no significant **differences in self-reported** measures of **cognitive load** between **students**

with and without prior exposure to learning content. An explanation of why prior exposure

did not have a significant effect **on cognitive load** might be found **in the**

design of Celestial Blast, since Celestial Blast was not

designed to meet the individual **needs of students with and** without prior exposure **(and**

instead was designed to examine the effect of prior exposure). Therefore, when designing GLAR applications, it is important to note that a GLAR application designed for novice students may not reduce the cognitive load of experienced students and vice versa (Sweller, 2003). We could have also observed no differences in cognitive load findings because reporting contexts were different. That is, novice students could have reported cognitive load based on the complexity of the learning material while experienced students could have reported cognitive load based on the difficulty of the game play. Quotes from the focus group qualitative data supports this explanation. Novice participants mentioned, "Since I didn't know the angles I had to think harder to remember what the classification was and it made me a little stressed," and likewise, "It was hard for me to make connections between the angles and incoming asteroids… I wish I would have known more about angles before playing the game." Whereas, experienced stated "I felt 97 stressed being the game because it was too many asteroids coming," and similarly, "Sometimes when I got to a higher level all the asteroids were mentally demanding." 3.7.3 Content-based learning gains (Research question 3) The differences in median pre- and post-assessment scores for novice students was found to be significant. The positive increase in content-based learning gains for novice students may be attributed to the instructional design of GLAR using CTML. That is, Celestial Blast's design successfully helped novice students learn the relevant content as evidenced by the significant difference in pre- and post-assessment scores. There were no significant differences for content-based learning gains for experienced students. This result was somewhat surprising because CTML suggests students with prior exposure to learning content should also experience content-based learning gains. These findings may be due

to the expertise reversal effect. The expertise reversal effect is the **phenomenon** whereby students **with prior**

exposure to learning content "experience either neutral or sometimes negative effects when utilizing technology meant to reduce cognitive load for students without prior exposure to learning content" (Blayney et al., 2010; Kalyuga et al., 2003). Although CTML assumes that prior knowledge is necessary to overcome these limitations of working memory, Paas and Ayres noted that when processing new information there are working memory limitations (Paas & Ayres, 2004). According to Sweller (1988), the reversal is due to the redundancy of processing

information that is already stored in the long-term memory. As a result, the

experienced students having prior exposure to the learning content may not need the same guidance that novice students need when using GLAR applications. Lastly, the learning gains of novice students

were not found to be significantly different than the learning gains of experienced students.

Both students with and without prior exposure had increased learning gains of approximately ten percent. We contributed these findings to lower order of thinking required to play Celestial Blast. This supposition is better understood by categorizing the level of thinking involved in playing Celestial Blast using Bloom's Revised Taxonomy (Anderson and Krathwohl, 2001). Bloom's Revised Taxonomy is the interaction of two dimensions (1) knowledge, and, (2) cognitive process (see Figure11). In the context our study, both novice and experienced students needed factual understanding (knowledge dimension) of basic elements regarding angles such as points, lines, line segments, and rays. Additionally, we believe that remember, understand and apply (cognitive process dimension) are most closely associated with the cognitive processes students utilized when interacting with Celestial Blast. Using this taxonomy, Celestial Blast primarily engaged students in lower order thinking that corresponds to the learning object Respond (circled in Figure 11). Figure 10. Bloom's Revised Taxonomy Note.

Each of the colored blocks shows an example of a learning objective that generally corresponds with each of the various combinations of the cognitive process and knowledge dimensions

(Anderson & Krathwohl, 2001). During Celestial Blast, lower order thinking occurred when the students were asked to employ factual knowledge to identify and classify the incoming asteroids' angle of attack as right, obtuse and acute. Once identified and classified, participants used the turret to measure and then destroy asteroids. Since this was a repetitive routine of shooting asteroids and did not require the students to participate in higher-order thinking (such as manipulating the learning content to hypothesize or arrive at new conclusions), we believe both students with and without prior exposure to learning content were able to obtain a greater understanding of angles. Research conducted by Micheller (2002) suggests that to determine differences between students with and without prior exposure to learning content, a higher-order of thinking when using GLAR may be required. Therefore, future studies should investigate if engagement with higher order thinking has an effect on content-based learning gains. 3.7.4 Implications

The results of this study suggest the importance of considering prior knowledge and

limitations of working memory when designing GLAR applications. Additionally, this study indicates that an emphasis should be placed on considering the differences in

prior knowledge when creating multimedia AR instruction. Further, it is important to note that a GLAR application that supports novice students may not necessarily support the cognitive processes of experienced students (and vice versa). This work also suggests that teachers could use GLAR in classrooms as a supplemental tool to

assist students in developing and understanding of the basic principles of angle identification and classification

as well as how to measure angles. The

results of this study indicate the use of GLAR to be most effective for

novice students who have not been exposed to learning content. Celestial Blast appears to have helped novice students gain a greater understanding of angles, which we propose provides a strong foundation to succeed in more advanced angle topics. Instructional designers should consider the importance of prior exposure when designing tablet- based GLAR applications, by for example, (1) increasing students' game play time, (2) developing separate applications, (3) using a scaffolding technique, and/or, (4) allowing students to select their starting game level. This study provides students' perceptions of the benefits of interacting with GLAR applications grounded in CTML and these perceptions could in turn be used to influence the design of future GLAR applications. Students support the idea that the use of gamification elements, understanding learning content, engagement, game functionality and plearning were beneficial to GLAR game performance. Our results further support the idea that the use of gamification in developing AR grounded in CTML facilitates positive game performance by creating tangible and interactive learning experiences. Lastly, although we did not close the content-based learning gap between novice and experienced students in this study, the utilization of tablet-based GLAR offers promise to help equalize the differences between student with and without prior exposure. Further research is needed to provide empirical evidence that GLAR could help be an equalizer. 3.7.5 Assumptions and Limitations There were a few assumptions made in this study. First, it was assumed that novice participants were not exposed at all to the relevant learning content during the 2016-2017 academic school year. However, it is difficult to account for this because participants could have been exposed to the learning content in an after-school program or at home and this possibility was not explicitly captured. Another assumption was that the experienced group consisted of participants with the same background knowledge, which may not be accurate. Within and between groups, all participants had varying levels of knowledge because they had different teachers and came from different schools. Another assumption made was that fifth-grade students have the ability to self-report the amount of cognitive load they experience during the gamified AR activity. To support this assumption, it should be noted that researchers Gopher and Braune (1984) found that elementary students were more than capable at providing a numerical value to assess their perceived stress, frustration and mental effort.

One limitation of this study was the number of participants. Because the small sample size of 35, it is difficult to generalize the results of this study. However, the results can be reasonably generalized to fifth grade students who live in lower socioeconomic condition and attend Title I schools in Virginia. Also, the sample of participants was not fully random due to gaining access to the specialized population. Another limitation of this study is that participants preferred cognitive style may or may not be supported by the design of Celestial Blast. This individual factor could have an impact on cognitive load, and since cognitive style was not assessed, researchers were not able to determine if self-reported cognitive load scores were affected. Note that the effect of cognitive style on GLAR and learning performance is the subject of Study 3 (see Chapter 5). A final limitation of the study was getting participants to fully engage in focus groups activities to discuss their opinions, thoughts, and perceptions. To help mitigate, at the beginning of focus group session, the moderator stated that the group was a “safe” and judgement-free space for everyone to contribute. 4 Applying CTML Principles to Gamified Learning AR Applications 4.1 Introduction Recently, the increased development and deployment of technology has made it possible for students to be immersed in new and engaging learning environments. Technology can help facilitate and increase learning as well as engage students in learning opportunities through collaboration and simulation (Carmigniani et al., 2010). As technologies start to transform K-12 classrooms, researchers have to further investigate how to design technology user interfaces that are effective for learning but do not unnecessarily place additional burdens on students’ cognitive load. Although a variety of instructional design frameworks and principles exist that focus on the design of the technology, there is no framework that serves as a best-fit for every instructional situation (Gregory & Chapman, 2012). According to Gustafson and Branch (2002), there are more published instructional frameworks than there are unique learning environments for them to be applied to! Therefore, it is important to identify appropriate frameworks or principles that are applicable for GLAR applications and further take into account the relationship between cognitive load and student learning. Research in cognitive education that takes into account the limitations of students’ working memory has identified the importance of designing multimedia learning content that does not overwhelm students with the ultimate aim of increasing student outcomes. Researchers suggest that educators should follow the recommendations of Mayer’s Cognitive Theory of Multimedia Learning (CTML) as they develop technology to be implemented in K – 12 learning environments (Burkes, 2007; Sorden, 2005; Gerjets et al, 2004; Mayer, 2009). CTML acknowledges the limitations of working memory to facilitate learning by not overloading the cognitive abilities of the student (Ayres, 2006). Leveraging CTML will allow researchers to structure how best to present information while simultaneously reducing students’ cognitive load. Therefore, a goal of this work is to determine if CTML is appropriate to guide the design of GLAR applications.

To achieve this, we conducted user studies to examine how the manipulation of CTML affects students' cognitive load. 4.2

Purpose of the Study Specifically, this study aims to examine if

principles provided by CTML can appropriately be applied to GLAR to maximize students' cognitive resources to reduce cognitive load and determine whether or not adherence to CTML principles is associated with positive student GLAR performance. Although GLAR is a captivating educational tool, research suggests that it is not AR itself that is important to improving the quality of learning (Dede, 2016). Therefore, we posit that principles of CTML are good candidates to guide the design of GLAR, foster meaningful pedagogy and reduce students' cognitive load. Since there is limited empirical research on what specific principles of CTML can reduce cognitive load, determining which principles of CTML may reduce cognitive load in GLAR is an area of research that needs to be addressed. However, Mayer claims that coherence, signaling, temporal contiguity and spatial contiguity will help with the reduction of cognitive processing. For this study, we chose to examine those four principles of CTML: coherence, signaling, temporal contiguity and spatial contiguity to investigate Mayer's claims. These principles will guide the design of three GLAR applications and determine how student cognitive load is affected by manipulating the degree to which GLAR interface designs adherence to these principles. We will measure cognitive load effects via cognitive load surveys administered after students interact with the three GLAR applications, each embodying different levels of adherence to four CTML principles. The results of this study will enhance the understanding of how manipulating coherence, signaling, temporal and spatial contiguity principles of CTML affects student cognitive load. We expect that this work will inform researchers of the educational benefit of using CTML to appropriately influence the design GLAR applications. Further, this study will reveal if the principles applied to a GLAR application will help or hinder students' performance. 4.3 Related Works 4.3.1 Cognitive Theory of Multimedia Learning (CTML)

When discussing learning theories, it is important to understand what signifies learning and

how cognitive architecture impacts learning

(Sweller, Van Merrienboer, & Paas, 1998). CTML is based on the human cognitive architecture and supports the

supposition that (1) working memory has capacity limitations, and, (2) the brain can effectively process information using both the auditory and visual channel.

According to Mayer (2010), CTML supports the notion that people learn better with audio and visual information presentation than

with audio or visual presentation alone. CTML explains how if technology is designed properly, people can leverage its attributes to effectively process information through visual and auditory channels by leveraging three important cognitive processes: selecting, organizing, and integrating (Moreno & Mayer, 2001). These cognitive processes are necessary in

order for learning to occur. If the technology is cognitively demanding (e.g., above and beyond the cognitive demand of the learning content), students will not be capable of

selecting, organizing and integrating new information with prior knowledge because their available working memory capacity

will be consumed by the cognitive overhead demanded of the technology (Mayer, 2009).

CTML provides a framework for understanding how students learn in a technology included environment (Mayer, 2009).

This theory offers explicit design principles to instructional designers to help reduce cognitive load demands on the student and increase the retention and transfer of targeted learning content. When implemented into applied technology for learning, the principles provide guidance on how to develop multimedia technology that improves students learning by effectively presenting the learning content. 4.3.2 CTML's Design Principles Educators are increasingly relying on technology to deliver learning content to students. Research shows that technology can achieve significant learning outcomes when it is explicitly

designed to take the student and human cognitive limitations into consideration

(Paas, Renkl, & Sweller, 2003; Clark, Nguyen, & Sweller, 2005; Sweller, 2005). According to Jones et al., (2010), the cognitive capabilities for interpreting and integrating information is limited for some students. Therefore, CTML provides design principles for the creation of multimedia instructional technology that focuses on efficiently responding to students' cognitive resources and "help learners integrate new information with prior information they already understand" (Mayer, 2005; Mayer & Moreno, 2010; Moreno & Mayer, 2010). Utilizing

CTML principles to design instructional technology has been shown to result in deeper learning

and reduced

cognitive load by using both visual and auditory working memory

channels (Mayer, 2009; Sweller, 2010). Essentially, the principles give guidance on how to best combine audio and visual information presentation to manage cognitive load, and reduce extraneous load processing

(Mayer, 2009). Extraneous load is the strain placed on working memory by

having students select, organize and 107 integrate unnecessary information (Sweller et al., 1998). Presenting information that distracts the student and is not necessary for accomplishing the learning objective will results in increased extraneous load and can hinder the learning process (DeLeeuw & Mayer, 2008). Extraneous load can be controlled by effective instructional design of the learning

content. Mayer identified four specific CTML principles that help

with the reduction of extraneous load and management of cognitive load

processing: coherence, signaling, temporal contiguity and spatial contiguity (Mayer, 2009). The objective of the coherence principle is to reduce extraneous load by eliminating irrelevant visual and auditory information (Mayer, 2005). According to Clark and Mayer, this is the single most important principle as cautious selection of visual and auditory information is needed to ensure maximum learning outcomes. Most studies that examine the coherence principle

have reported that the inclusion of extraneous information hinders learning (Bryant, 2010;

Lusk, 2008; Mayer et al., 2008; McCrudden & Corkill, 2010; Rowland et al., 2008; Rowland-Bryant et al., 2009; Verkoeijen & Tabbers, 2009). For example, a study

conducted by Garner et al. (1989) examined how adults' and college students' learning was affected when given selective passages with and without irrelevant details included in a narrative. Researchers found that the addition of irrelevant both aural and visual information decreased the processing of the main idea of the passage for both adults and college students (Garner et al, 1989). Additionally, Lehman et al., found that the inclusion of extraneous information may cause the student to incorrectly assume that the irrelevant information is the primary objective and incorrectly construct a mental model around the irrelevant information (Lehman et al, 2007). It was concluded that the disruption in constructing a correct mental model hinders the student from the true learning objective and achieving content-based learning gains. Mayer, Heiser and Lonn (2001) conducted a study to investigate the addition of college-aged video clips to make the presentation of information more interesting. Researchers

had one group of students view a three-minute narrated amination on lighting formation while the second group

of college-aged students viewed the same presentation containing an additional one-minute video clip that was related to lighting but not the primary objective of the presentation. The study concluded that the students in the second group performance was hinder when competing problems regarding the formation of lighting. Adding the unnecessary visuals increased extraneous load processing (Mayer et al, 2000). Similarly, to adding unnecessary visual information, Moreno and Mayer (2001) found that adding unnecessary audio can also increase cognitive load. Moreno and Mayer performed a study to examine the transfer of knowledge by having college-aged students view a multimedia presentation containing animation and concurrent narration. The first group of students received either no additional audio, background music, nor sounds effects and the second ground received both background music and sounds effects. This study found that students who received

both sounds and music performed worse than groups not receiving audio.

Also,

students in the second group performed worse than the first group. From the

results reported in these studies, Mayer suggests taking a minimalist approach to design in which only the relevant material needed to achieve instructional goals is included. However, there are some criticisms that these studies were all preformed in a laboratory setting and with adults or college-aged students (McTigue, 2009). Research suggest that further studies are needed to examine how the inclusion of extraneous information can affect K-12 students in an authentic learning environment

(Harskamp et al., 2007; Issa et al., 2011; Muller et al., 2008).

The

objective of the signaling principle is to reduce extraneous cognitive load by

highlighting essential learning content so students are able to organize and comprehend the content being presented (Mayer & Moreno, 2003). Signaling uses cues to highlight and direct students' attention to significant information (Mautone & Mayer, 2001). By using cues, students do not utilize unnecessary cognitive resources locating information or integrating nonessential information into their memory schemas. According to Mayer, students learn more effectively when cues are used to guide their attention to vital information (Mayer, 2010). To evaluate the effectiveness of signaling, Mautone and Mayer (2001) used dynamic cues to highlight important information in an animation that explains to participants how airplanes lift.

Although the effect size of this study was small, the study found

that participants showed positive cognitive benefits when exposed to signaling within animations. Mayer and Moreno (2003) investigated the role of auditory cueing when highlighting important information

and found that students who received animation using narrated cues outperformed students who

did not receive any auditory cues when asked to solve problem-solving transfer questions. According to Katzer and Treue (2006) the use of auditory cues is more attentional than visual cues at orienting the student to focus on essential information that has been highlighted. Beck (1987 and 1990) found that students who received visual cues such as arrows, labels and pointers to identify critical information in animations outperformed their counterparts who had no visual cues. Through the use of visual cues, Beck concluded that students were able to conduct memory traces based on dual retrieval and reinforce critical information into their working memory (Beck, 1987). Additionally, Tabbers, Martens & Merrienboer (2004) believed that "adding visual cues to illustrations resulted in higher student retention scores." Although visual and auditory cues are processed differently, using both cues simultaneously reduce demand on working memory (Moreno & Mayer, 1990). Janelle et al (2003) found that students demonstrated less errors and increase retention of learning content when using video modeling to present information with both visual and auditory cues as compared to students who just received visual cues. Their results bolster the claim that processing auditory cues in addition to congruent visual cues “enhances perceptual representation and retention” and thus can reduce cognitive load (Janelle et al., 2003). While the inclusion of signaling eliminates distractions, decrease search time of important information and help decrease cognitive processing in the working memory, there is more empirical evidence needed to examine the use of color coding as a viable signaling cue (DiVita, Obemayer, Nugent, & Linville, 2004). Although color coding allows participants to build mental models in which colors are connected with certain information, such encodings could also increase cognitive load when many sets of color coding are utilized in a visual display. The aim of the temporal contiguity principle is to reduce extraneous load by presenting auditory and visual information simultaneously. According to Mayer, students learn better when multimodality presentation of information is temporally synchronized rather than separated in time (Mayer & Moreno, 2003). Separating information in time forces students’ cognitive resources to hold the one channel of information (e.g., aural) in their working memory until the other channel (e.g., visual) is presented (Fletcher & Tobias, 2005), which can result in increased extraneous load and reduced content-based learning gains. Studies show that temporal contiguity helps students make more significant connections between relevant pieces of information. For example, Moreno and Mayer (1998) conducted a study that delivered information on lighting to college-aged students using narration and animation. The first group “viewed the presentation of animation and narration concurrently” and the second group viewed the animation presentation in it entirely then viewed the narration. This study concluded that students in group one significantly outperformed students who did not view the information simultaneously. Additionally, Mayer and Anderson (1991) found that students’ transfer of knowledge was significantly higher when they viewed an animation simultaneously with narration explaining how pumps work in comparison to students who viewed an animation after the narration was played (Mayer & Anderson, 1991). There are multiple studies that replicated a similar format to examine temporal contiguity in different subject areas (Kalyuga & Sweller, 2004; Mayer & Sims, 1994; Mousavi et al., 1995). These studies all conclude that presenting auditory and visual information at the same time rather than in succession increases transfer of knowledge and reduces cognitive load by utilizing dual coding. The purpose of the spatial contiguity principle is to coordinate information in space to lessen cognitive demands on working memory (Mayer, 2005). When related multimodal information are presented in spatial proximity, working memory cognitive demands are reduced by reducing the

amount of time **students have to hold** the information **in their working memory while**

they acquire additional information. When applying the spatial contiguity principle to reduce extraneous load, only information relevant to the learning task should be included so students are not forced to decide what information requires their attention (Mammarella, Fairfield, & Di Domenico, 2013). Research conducted by Chandler and Sweller examined the effects of spatial contiguity on learning by separating text from diagrams. They proposed that students would experience increased cognitive load because extra processing was needed to integrate the spatially separated information in working memory (Chandler and Sweller, 1991). The study concluded that students who viewed information in high spatial proximity had increased performance in both written and practical skill demonstrations. Mayer (1989) also investigated spatial contiguity by presenting college-aged students on-screen text both near and far from corresponding visuals depicting automotive braking systems. This study revealed that students can transfer more information on post- assessments when information presented in proximity (as compared to when information is not proximal). Furthermore, Mayer stated “learning is impaired when on-screen text is spatially separated from visual materials” (p.366). When solving practical problems, Tindall- Ford, Chandler, and Sweller (1997) found that students learn better when instructions are placed near diagrams as opposed to students who received instructions placed below the diagram (Tindall- Ford et al., 1997). The aforementioned studies suggest that placing relevant information spatially near each other reduces extraneous processing; however, there are no studies that gives specifics metrics on how spatial contiguity could help with the creation of new mental models (Mayer & Sims, 1994). Therefore, further research is needed to understand exactly where diagrams and text information should be coordinated to minimize students having to hold information in their working memory. Numerous studies conducted by Mayer and colleagues show significant conclusions on how leveraging the aforementioned principles of CTML will optimize students’ learning experiences in multimedia presentations such as animations, PowerPoints and web interfaces. However, these principles have been investigated individually rather than examining how they may interact with each other. According to Johnson (2008), considering the principles as non- interacting factors may lead to overconfidence that CTML is effectively guiding multimedia technology design that reduces extraneous load and manages cognitive load processing. Additionally,

there is limited **research** in **the application of** CTML principles **to the design of**

augmented reality technologies such as GLAR applications. Therefore, a contribution of this work is the examination of how adherence to multiple, interacting CTML principles in an augmented reality learning application may reduce students’ cognitive load. 4

.4 Research Questions The study addresses the following research questions:

Research Question 1: Does GLAR interfaces’ level of adherence to CTML principles affect students’ cognitive load? 113 Hypothesis (H1): Students’ cognitive load is significantly lower when there is high adherence to the principles of CTML. Research Question 2: Does high adherence to the principles of CTML result in higher students’ GLAR performance? Hypothesis (H2): High adherence to the principles of CTML does result in higher students’ GLAR performance. 4.5 Study Overview This study used a single factor repeated measures within-subjects experimental design to measure the effects of adhering to different principles of CTML on student cognition. A repeated measures

design is frequently used in psychological **research** when **it is** desired **to**

compare different treatment effects while reducing error variances by using participants as their own control (Lindsey, 1999). In this design, participants are being measured using the same cognitive load and user satisfaction scales to show comparisons between means obtained after the participant interacts with each of the three interfaces. Using repeated measure allows researchers to determine which interface will reduce cognitive load as well as which interface will cause the most cognitive load in participants. For this study, the single factor is the GLAR application (Celestial Blast) manipulated at three levels with respect to adherence to CTML principles: high adherence, medium adherence, low adherence (described in detail below). The manipulation systematically added and removed specific auditory and visual user interface components. Even though the three interfaces were visually and aurally different (due to experimental manipulations), each interface contained the same learning content and overall game play. 4.6 Independent Variable: Celestial Blast Adherence to CTML Principles Similar to study one, the Celestial Blast tablet-based AR application was used to manipulate the main independent variable. For an explanation of Celestial Blast (see section 3.4). For this study, we created three different variants of Celestial Blast to examine how different levels of adherence to four CTML principles i.e., coherence, signaling, temporal contiguity and spatial contiguity when designing GLAR applications effects participants' cognitive load, performance and satisfaction. ? High Adherence Interface: strictly adheres to CTML principles to reduce the amount of cognitive load participants utilize when interacting with GLAR. ? Medium Adherence Interface: slightly deviates from the principles of CTML increasing the amount of non-relevant information presented while providing participants with minimal indication of important information. ? Low Adherence Interface: aims to overload participants with information in the visual channel without highlighting significant information. The aims of Medium and Low adherence interfaces were deviate from the principles of CTML to examine if participants' cognitive load increases. 4.6.1 High Adherence Interface This section details how the four principles of CTML were manipulated in the design of the high adherence interface of Celestial Blast (Figure 12). For coherence, it is essential to only present the participants with relevant information. Thus, the high adherence interface included the following information: angle number, angle classification, ammunition indicator, score, town's health, SOL question and on-screen text notifications when participants cleared a level and earned bonus points. These seven pieces of information were presented because they are relevant to the participant successfully completing the mission of protecting the town. For the signaling principle, cues were used to highlight significant pieces of information presented. Aural voiceover cues were used to highlight incoming asteroids that require the participants' immediate attention. The voiceover is a female human voice that alerts participants of incoming asteroids once an asteroid is within 5 degrees of hitting the town. The region to attend to is signaled; therefore, if an asteroid was coming in at 20 degrees and within 5 degrees of hitting the town the cue would say "Asteroid coming is acute. Other important information such as the town's health was also signaled using color and shape. Specifically, when the town is in a healthy state it is green and its corresponding health bar is fully illuminated. After the town has been hit once, the town shape will change from green to yellow and the health bar will decrease by one. The final interface element manipulated via signaling principle is the ammunition indicator that decrements by one every time a participant fires the laser. The spatial contiguity principle was applied to the high adherence interface by coordinating related information and placing them in close spatial proximity. The angle degree and region in which the turret was pointed is placed together under the image of the turret so participants can quickly identify the position of the turret. Displaying text of the incoming asteroid angle number directly on the incoming asteroid helps participants build representations and identify the region to move the turret. For example, seeing an incoming asteroid with a text label of “141” allows the participant to quickly acknowledge that the asteroid is in the obtuse region. Lastly, SOL questions participants must answer to regain ammunition and the visual answers to the questions were displayed at the same time so participants would not have to remember the question then see the corresponding answers. For temporal contiguity, audio and visual information is presented simultaneously. For example, when the laser is accurately fired at an asteroid the participant hears an explosion acknowledging the asteroid is destroyed, and simultaneously the number of points earned is visually displayed (e.g., +30) along with an auditory alert (e.g., “You have earned 30 points”). Further, when a level is cleared, on-screen text visually appears (e.g., “Level 5 Cleared”) and participants receive a simultaneous auditory alert (e.g., “Good Job! You have cleared another level”). Figure 11. High Adherence Interface for Celestial Blast 4.6.2 Medium Adherence Interface The medium adherence interface (Figure 13) of Celestial Blast manipulated the four CTML principles in different ways. For coherence, four additional pieces of information were added (above and beyond information presented in the high adherence interface): town health statistics, background music, sound effects and two towns participants did not have to protect. These additions presented participants with irrelevant information, which was intended to demand unnecessary cognitive resources to determine what information is most important to achieving the mission of Celestial Blast to protect the ploof’s town. These four pieces of information was selected based on feedback we received from user studies conducted in the COGENT lab at Virginia Tech. For the signaling principle, the health bar and ammunition indicator cues were removed, which we hypothesized would hinder participants’ ability to understand what resources were available to help protect the town. Removing signals also increases their cognitive load because the participant needs to search for additional information to understand how to play the game. The voiceover cues were modified to no longer highlight significant information and instead announced every third asteroid even if the cued asteroid was not a threat to the town. Our hypothesis was that deviation from the signaling principle would force participants to integrate information in working memory that utilizes unnecessary cognitive resources. Spatial contiguity was manipulated by increasing the amount of space between the presentation of images and on- screen text by 1.5 inches (when displayed on an eight-inch tablet). For example, the angle classification and specific angle increased spatially in the horizontal dimension by 1.5 inches. Our hypothesis was that increasing the distance between information elements would increase the cognitive demands in working memory because participants have to hold information such as angle number

in their working memory while they search for related **information**

such as angle classification. Lastly, five second temporal delays were added to

the presentation of aural **and on- screen text.** Adding temporal and **visual** delays to **the**

medium adherence interface made it difficult for participants to make significant connections between information. For example, when participants clear a level, text is displayed (e.g., “Level 5 Cleared”), however, the accompanying auditory alert (e.g., “Good Job! You have cleared another level”) did not render until 5 seconds later. Figure 12: Medium Adherence Interface of Celestial Blast 4.6.3 Low Adherence Interface The low adherence interface (Figure 14) was designed to increase the cognitive load demand of participants which in turn, we hypothesized would negatively affect task performance. The coherence principle was manipulated by adding four random pieces of unnecessary visual information: timer, astronaut, positive feedback delivered via on-screen text, and a UFO. These four pieces of unnecessary visual information was selected based on feedback we received from user studies conducted in the COGENT lab at Virginia Tech. Presenting participants with unnecessary and unrelated content increases extraneous load and making connections between irrelevant pieces of information may impose a high cognitive load. The increase in cognitive load occurs when the participant must split their attention between integrating multiple pieces of information into their working memory. All cues to highlight significant information were removed from the low adherence interface. Without selective attention cueing, participants

have to split their attention between multiple pieces **of information and**

may not be able to identify important information from irrelevant. To manipulate the spatial contiguity principle, the space between images and on-screen text was increased to 3 inches horizontally (as views on an eight- inch tablet). For temporal contiguity, the presentation of audio and on-screen text was delayed by 10 seconds. Thus, when a participant accurately destroyed an asteroid, the sound acknowledging the laser had been fired was played ten seconds after the explosion. We hypothesized that separation of audio and visual information forced participants to expand their mental efforts by directing their cognitive resources to encode the visual information in their working memory until the audio cue was played. Figure 13. Low Adherence Interface of Celestial Blast Table 16: Summary of Celestial Blast Interface Conditions Celestial Blast Interface Condition CTML Design Principle High Adherence Medium Adherence Low Adherence Coherence Seven pieces of information: 1. Health Bar 2. Ammunition Indicator 3. Angle Classification and number 4. Score 5. SOL Question 6. Voice Alerts 7. On-Screen Text Notification (i.e. Level Cleared) Eleven pieces of information (4 additional pieces of information as compared to high adherence) 8. Town health Statistics 9. Two additional towns 10. Background music 11. Sound effects Fifteen pieces of information (4 more pieces of additional information as compared to medium adherence) 12. Game timer 13. UFO 14. Astronaut 15. Positive Feedback Signaling 1. Voiceover Cues 2. Town changing color 3. Health bar 4. Ammunition Indicator 5. Color coding Eliminate three signals: 1. Health Bar 2. Ammunition Indicator 3. Voiceover Cues were still present but not used to highlight significant information No signaling present Spatial Contiguity 1. Angle degree and region of turret 2. Angle number and asteroid 3. SOL question and answers Increase spatial placement horizontally by 1.5 inches Increase spatial placement vertically by 3 inches Temporal Contiguity 1. Laser fired and explosion 2. Points received and audio alert 3. Level cleared notification and audio alert Increase temporal delays by 5 seconds Increase temporal delays by 10 seconds 4.7 Dependent Measures The dependent variables of the study were average game score, highest game score, number of plays and cognitive load scores. The dependent measures were collected through self-reported cognitive load surveys (NASA TLX), and GLAR game metrics. ? GLAR performance: average score across all games played, highest score achieved, and number of game plays. Students had the freedom to fail and replay Celestial Blast multiple times within the allotted time, the number of game plays ranged from 1 (best) to infinite (worst). ? Cognitive load scores: average workload from NASA TLX survey ranged from 0 (lowest workload) to 1 (highest workload). 4.8 Methodology Each participant was exposed to all three adherence interface conditions. After each interaction with an interface, participants completed a cognitive load survey and user satisfaction survey. The sequence in which participants experienced different adherence interface conditions using a three by three Latin square to mitigate ordering effects such as those associated with practice and fatigue. The dependent variables were game scores, perceived cognitive load, and user satisfaction scores. To measure the effect of adherence of students' cognitive load, participants self-reported their mental workload after interacting with the three experimental conditions of Celestial Blast. To assess participants' GLAR performance, we collected game scores achieved after exposure to each experimental condition of Celestial Blast and user satisfaction scores from user satisfaction surveys. 4.8.1 Participants Understanding the target population is a crucial component of

establishing a valid experiment with reliable data and conclusions (Creswell,

2009). Most of the existing literature investigating AR as an educational tool has included students in higher education such as those attending community college and four-year universities (Appleton, 2005). Also, according to McTigue (2009), most

of the research on **CTML** principles **has** primarily **been conducted** with **college-** aged **students**

in a laboratory setting and not applied to younger populations. To expand on the body of literature, the target population for this study was fifth grade students from Title I schools in the Virginia Public School system. Title I is a funding program provided by the U.S. Department of Education to "assist low income and at-risk students who are struggling academically to obtain a high-quality education and reach, at minimum, proficiency on challenging state academic achievement standards and assessments." A purposive group of 22 students from two different schools in the Southwest region of Virginia were recruited. Each school had fifth grade classroom sizes between 9 and 16 students. All students had completed a public education through grade four and passed Virginia SOLs in order to move on to the fifth grade. We gained access to students through the Virginia's Tech Kindergarten-to-College (K2C) program. This program was developed to educate potential first-generation college students about pursing a higher education. The program brings fifth grade students from Title I schools in Virginia to Virginia Tech's Blacksburg campus to participate in STEM activities and gain first-hand exposure to cutting-edge research and technology. Based on the 2016 Mathematics Standards of Learning Curriculum Framework academic calendar, it was assumed that all students had been introduced to mathematics learning content on geometric angles during the 2016-2017 academic school year and had a basic understanding of a protractor. The basic understanding of a protractor allowed the students to accomplish the goal of Celestial Blast. 4.8.2 Research Setting This research was conducted on Virginia Tech campus in a controlled classroom. Study one utilized the same research setting to collect data on understanding the role of prior knowledge on participants' perceived cognitive load. For more details, see section 3.5.4. 4.8.3 Instrumentation 4.8.3.1

NASA Task Load Index (TLX) **NASA TLX is a** direct, **subjective**

measurement of participants' perceived cognitive load after interacting with a GLAR application. We also used NASA TLX in study one to measure mental workload. See section 3.5.5.2 for a detailed description of NASA TLX. 4.8.3.2 User Satisfaction Survey A 12-question post activity evaluation survey was developed to gather participants' attitudes of CTML design principles, presentation of learning content and overall perceptions of the adherence interfaces (e.g., which interface were perceived to alleviate cognitive load and increase the understanding of the leaning content). This survey was adopted from the

Questionnaire for User Interaction Satisfaction (QUIS) 7.0 (Harper, Slaughter, & Norman, 1997).

QUIS measures participants'

perception of an **interface through assessment of the** participants' **subjective satisfaction.** The QUIS was **proven**

to be reliable and valid after extensive testing and seven revisions. Also, according to the SMOG Index, Gunning Fog formula and Coleman-Liau Index the understandability and reading level of QUIS corresponds to a fourth grade level which indicates it is an appropriate instrument to use with elementary aged students. Questions were 124 phrased to elicit forced-choice,

5-point Likert scale responses **ranging from 1=** no, **to** 3=maybe, **to**

5=yes. Examples of questions include: Was too much information presented? Did the auditory alerts help you protect the town? See Appendix H, I, and J for the complete user satisfaction questionnaires. For this dissertation work, we did not formally assess the results via statistical analysis; however, Appendix O contains simple descriptive statistics for the complete user satisfaction questionnaire. 4.8.4 Data Collection Procedure This study employed a five-step process. First, participants were introduced to the primary researcher and undergraduate developers of Celestial Blast. The research team gave a presentation of game instructions and then demonstrated how to play Celestial Blast. The presentation and introduction and occurred

during the first ten minutes **of the** session. Next, **participants were randomly divided into** three **groups**

to control for the order in which groups of participants experienced the three adherence interfaces. During game play, we walked around to assist participants if they had any questions on the learning content or AR interface as shown in Figure 4. For example, if a student was having trouble seeing the graphics, the researcher instructed the student to manipulate or move the AR marker, to increase or decrease their field of view. During each interaction, the participants were responsible for recording their game scores. After interacting with one adherence interface condition, all participants completed NASA TLX survey to self-assess their perceived cognitive load and user satisfaction survey. During the fourth and final steps, participants experienced the other two adherence interface conditions, as shown in table 4. Similar to step three, participants completed the NASA TLX and user satisfaction survey after interacting with the second and third Celestial Blast adherence interfaces. Table 17: 3x3 Latin square Step Three Step Four Step Five Group One High Adherence Interface Medium Adherence Interface Low Adherence Interface Group Two Medium Adherence Interface Low Adherence Interface High Adherence Interface Group Three Low Adherence Interface High Adherence Interface Medium Adherence Interface 4.9 Results 4.9.1 Research Question 1 Does GLAR interfaces' level of adherence to CTML principles affect students' cognitive load? 4.9.1.1 Descriptive Statistics For average workload, the unweighted NASA TLX scores were reported as a measure of

cognitive load. Descriptive statistics of cognitive load across adherences interfaces **are** reported **in table**

18. The data shows high adherence interface a median average workload of 0.23, with minimum and maximum average workload of 0 and 0.62 respectively. Medium adherence interface had a median workload of 0.40, with minimum and maximum average workload of 0.11 and 0.975 respectively. Low adherence interface had a median workload of 0.70, with minimum and maximum average workload of 0.26 and 0.92 respectively. Figure 14. Comparing Average Workload by GLAR Interfaces' Adherence Table 18. Descriptive Data for Average Workload by GLAR Interface Designs Percentile Interfaces M SD n Min Max 25 50 75 High Adherence 0.311 0.155 Medium Adherence 0.410 0.235 Low Adherence 0.645 0.189 Note. Lower average workload is better 22 0 22 0.108 22 0.258 0.617 0.208 0.975 0.219 0.917 0.548 0.338 0.396 0.7 0.410 0.536 0.796 4.9.1.2 Hypothesis Testing Hypothesis (H1): Students' cognitive load is significantly lower when there is high adherence to the principles of CTML. A Friedman's test was conducted to evaluate differences between GLAR interfaces' level of adherence to CTML principles

on median change in students' average workload **scores. The test** for average workload **was significant;**

therefore, we know at least one of the GLAR interfaces has a median different from the others. Table 19. Average Workload Friedman's Test Result n Chi-square df p-Value Average Workload 22 30.220 2 <0.0001* To test hypothesis 1, a post-hoc Wilcoxon pairwise comparison for Friedman's tests was conducted using Bonferroni Correction. If the p-value is less then ? where m ? # of pair-wise 2m comparisons to be made which would typically be ?? 2 ?? if all pair-wise comparisons are of interest. ? k ? For this experiment, we can make a total of m = ? ? ? 3 pair-wise comparisons so we compared ? 3 ? ? 2? .05 p-values to ? .00833 . When comparing the p-values to 0.008 for both average workload and 2(3) mental demand scores, we concluded

that there is significant difference between low adherence interface **and high** adherence interface **as**

well as between low adherence interface and medium adherence interface. When comparing medium adherence interface to high adherence interface,

we fail to conclude that these interfaces **differ** significantly. Since **the p value**

was not significant for the high adherence interface, the hypothesis was accepted. The comparisons identified that students' cognitive load is significantly lower in the high adherence interface compared to the low and medium adherence interfaces; therefore, we accept the hypothesis. The effect size can be

calculated using the formula: r = Z , where **n** is **the** total **number of**

samples. The effect size is $\sqrt{n}$ considered large when it is more than 0.5, median when between 0.3 and 0.5, and small when less than 0.3

(Grissom & Kim, 2012). The effect size for **the** difference between **the** low adherence interface **and**

high adherence interface was r = 1.073. The difference between low adherence interface and medium adherence interface has an effect size of r = 0.878. The effect size for the difference between the medium adherence interface and high adherence interface was r = 0.342. Table 20. Nonparametric Comparisons for each Pair using Wilcoxon Method using Average Workload Scores Level - Level Z-Value p-Value r Low Low Medium High Medium High 5.035 < .0001* 4.119 < .0001* 1.608 0.108 1.073 0.878 0.342 4.9.2 Research Question 2 Does high adherence to the principles of CTML result in higher students' GLAR performance? 4.9.2.1 Descriptive Statistics For game metrics, average game score, highest game score and number of game plays were analyzed as measures of GLAR performance. Descriptive statistics for game performance across GLAR interfaces are summarized in tables 21, 22 and 23. The data shows high adherence interface a median average game score of 927, with minimum and maximum average game scores of 264.44 and 3686.67 respectively; median highest game score was 1560 respectively, with minimum and maximum highest game scores of 455 and 6120; and median number of plays was 4, with minimum and maximum number of plays of 3 and 9 respectively. Medium adherence interface had a median average game score of 533.75, with minimum and maximum average game scores of 320 and 4150 respectively; median highest game score was 1397.5 respectively, with minimum and maximum highest game scores of 495 and 4240; and median number of plays was 5, with minimum and maximum number of plays of 1 and 9 respectively. Low adherence interface had a median average game score of 597.5, with minimum and maximum average game scores of 146.67 and 2357.5 respectively; median highest game score was 1072.5 respectively, with minimum and maximum highest game scores of 205 and 4395; and median number of plays was 6, with minimum and maximum number of plays of 2 and 9 respectively. Figure 15. Comparing Number of Game Plays by GLAR Interfaces' Adherence Figure 16. Comparing Average Scores by GLAR Interfaces' Adherence Figure 18. Comparing Highest Game Scores by GLAR Interfaces' Adherence Table 21. Descriptive Data for Number of Game Plays by GLAR Interface Designs Percentile Interfaces M SD n Min Max 25 50 75 High Adherence 5.045 2.399 22 3 9 3 Medium Adherence 5.363 2.341 22 1 9 3.75 Low Adherence 5.545 2.219 22 2 9 3.75 4 5 6 6.75 7.25 7 Note.

Lower number of game plays resulted in improved GLAR performance Table 22. Descriptive Data for Highest Game Score by GLAR Interface Designs Percentile Interfaces M SD n Min Max 25 50 75 High Adherence 2162.36 Medium Adherence 1760.86 Low Adherence 1251.36 1564.23 1181.22 861.22 22 455 22 495 22 205 6120 853.75 4240 795 4395 803.75 1560 1397.5 1072.5 3493.75 2327.5 1476.25 Table 23. Descriptive Data for Average Game Score by GLAR Interface Percentile Interfaces M SD n Min Max 25 50 75 High Adherence 1179.92 Medium Adherence 911.31 Low Adherence 621.44 885.85 877.15 467.36 22 264.44 22 320 22 146.67 3686.7 44150 2357.5 438.36 434.89 320.17 927 533.75 579.5 1541.25 970.24 659.06 4.9.2.2 Hypothesis Testing Hypothesis (H2): High adherence to the principles of CTML result in higher students' GLAR performance. Three Friedman's tests were conducted to evaluate differences on median change in GLAR average game scores, highest game scores and number of plays between students when adherence to CTML principles were manipulated in GLAR interfaces. The Friedman's test for average game score and highest game score were significant; therefore, we know at least one of the GLAR interfaces has a median different from the others. The Friedman's test for the number of game plays was not significant. 133 Table 24. Friedman's Test Result for Average Game Score, Highest Game Score and Number of Game Plays n Chi-square df p-Value Average Game Score Highest Game Score Number of Game Plays 22 13.482 22 8.049 22 1.564 2 2 2 0.0012* 0.0179* 0.458 To test, hypothesis 2, post-hoc Wilcoxon pairwise comparisons for Friedman's tests on average game score and highest game score was conducted using Bonferroni Correction where we compared p-values to 0.00833. When comparing the p-values to 0.008 for highest game scores, we concluded

that there is significant difference between low adherence interface and high

adherence interfaces and has an effect size of r = 0.568. When comparing medium adherence interface to high adherence interface as well as low adherence to medium adherence interface, we fail to conclude that these interfaces differ significantly with effect sizes are r = 0.235 and r 0.393 respectively. When comparing the p-values to 0.008 for average game scores,

we accept the hypothesis and concluded that there is significant difference between

medium adherence interface and high adherence interface with an effect size of r = 0.458 as well as between low adherence interface and high adherence interface with a large effect size of r = 0.758. But when comparing low adherence interface to medium adherence interface, we fail to conclude that these interfaces differ significantly and the effect size of this comparison is r = 0.348. The comparisons identified the high adherence interface as being significantly higher when looking at students' GLAR performance. Table 25. Nonparametric Comparisons for each Pair using Wilcoxon Method using Average Game Scores Level - Level Z p-Value r Low Medium Low Medium High High -1.6314 -2.1478 -3.5561 0.1028 0.348 0.0317* 0.458 0.0004* 0.758 Table 26. Nonparametric Comparisons for each Pair using Wilcoxon Method using Highest Game Scores Level - Level Z p-Value r Medium Low Low High Medium High -1.185 -1.8426 -2.6641 0.2359 0.253 0.0654 0.393 0.0077* 0.568 4.10 Discussion The goal of this study is to (1) examine if principles provided by CTML can appropriately be applied to GLAR and reduce students' cognitive load, and, (2) determine whether or not adherence to CTML principles is associated with positive GLAR performance. Key results from the empirical study revealed that high adherence to CTML's principles was effective at (1) lowering students' cognitive load, and, (2) improving Celestial Blast performance. These findings are aligned to what is predicted by CTML (Mayer, 2005), but also bolsters multiple research studies in multimedia learning that show reduced cognitive load and improved performance when multimedia interface designs strictly adhere to CTML principles (Van Dusen, 1997; Lai et al., 2013; Kim & Kim, 2012). 4.10.1 Cognitive load (Research question 1) Mayer advocates for adherence to principles of CTML as an effective methodology

to reduce cognitive load and account for **the amount of information** that can process **at** one **time**

(Mayer & Moreno, 2002). According to Mayer, using the

coherence, signaling, spatial contiguity and temporal contiguity principles of

CTML will reduce and mange students' cognitive load. The results of this study support Mayer's claim by providing evidence that suggest high adherence to principles of CTML is helpful at efficiently reducing student cognitive load and moreover that derivation from CTML principles will significantly increase student cognitive load when using tablet-based GLAR applications. Thus, when interacting with the high adherence interface, students may not have to use as many

working memory resources **to select, organize and integrate** auditory and visual **information** which **in**

turn could be why we observed lower reported average workload. The observed increase in cognitive load when using the medium and low adherence interfaces could be from the students experiencing stress when trying to actively participate

in the cognitive processes of selecting, organizing and integrating.

This stress could have been attributed to (1) only using one modality in the low adherence interface or overloading the visual and auditory channels in the medium adherence interface, (2) organizing the visual and auditory content in an illogical manner, and/or, (3) complexity of the learning content. According to literature, when students are stressed they are not capable of fully participating in cognitive processes which contributes to cognitive overload and hinders students' performance (Chen & Chang, 2009; Eysenck & Calvo, 2002). 4.10.2 GLAR performance (Research question 2) Our study revealed that students interacting with the high adherence interface had significantly higher GLAR performance as compared to students interacting with the medium and low adherence interfaces. The observed low performance could be due to students being distracted by (1) the inclusion of unnecessary information not related to the learning content, (2) the absence of signaling, and, (3) the increase in temporal and spatial contiguity. Although we concluded that closely adhering to the principles of CTML could increase students' tablet-based GLAR performance, our findings do differ from earlier studies conducted using 2D multimedia technology (Chang, Chien, Chiang, Ming-Chao & Hsin-Chih, 2013; Savoy, Proctor & Salvendy, 2009). For example, Wolf (2009) found that adhering to CTML principle did not increase 136 performance using PowerPoint to deliver multimedia instruction to college aged students. While CTML's principles were designed to addresses presenting information in diverse multimedia materials and technologies to increase performance, adherence to the principles may not necessarily apply to the development of all technology as predicted by Mayer and colleagues (Mayer, 2009; Sorden, 2005; Burkes, 2007). The results of our study suggest that CTML's principles are potentially applicable and effective for designing tablet-based gamified augmented reality applications. Further research using tablet-based GLAR is needed to validate our findings. 4.10.3 CTML's Design Principles The satisfaction survey results found in Appendix O suggest that students were indifferent about the use of coherence in tablet-based GLAR. Students felt that presented irrelevant information such as background music and additional graphics, made the GLAR application more interesting and, therefore, more effective. This finding suggests that low coherence (e.g., interfaces with irrelevant information) may actually contribute to maintaining students' attention and increasing GLAR performance. Muller et al. (2008) suggest that contrariety to the coherence principle, multimedia designers should "include irrelevant but interesting audio, graphics, and text to increase students' interest and attention for the purpose of enhancing learning." The interesting but irrelevant information in Celestial Blast could have been for example, the dancing astronaut and flying UFO. Additionally, arousal theory concludes that emotionally arousing students with irrelevant but interesting information can result in increased motivation (Reisenzein, 1994). The assumption of arousal theory is students learn best when they maintain an optimal level of emotionally arousal. However, each student has a unique arousal level that is right for them. Thus, more research is needed to investigate the use of coherence while determining what is the appropriate inclusion of irrelevant but interesting information to keep each students aroused when interacting with tablet-based GLAR applications. Signaling: The data gathered from the satisfaction survey indicate that not adhering to signaling contributed to students' increased cognitive load. The mean score displayed in Appendix O indicates that students found the signaling principle to be effective at reducing the amount of

time and amount of information that students **held in** their **working memory**

as compared to coherence, spatial contiguity and temporal contiguity. These results echo results of other studies that found signaling reduced cognitive load by structuring information that guided students to the most pertinent information (Xing, 2006). The main advantage of using signaling in Celestial Blast was to draw students' attention to important information such as the ammunition indicator and health bar, and to use voiceover cues

as a cognitive guide to **helps** students **make sense of the**

game. Spatial contiguity: Survey results suggest that manipulation of spatial contiguity had an effect on students; interaction with GLAR. In the medium and low adherence interface, students could have experienced increased cognitive load due to the spilt-attention effect. According to Mayer, the spilt-attention effect can occur when the visual channel is overloaded such that searching for and identifying relevant visual information requires significant attentional and cognitive resources. For example, instead of isolating text from graphics, the integration of related information should be placed together to reduce or eliminate the split-attention effect (Paas et al, 2003). Therefore, effectively applying spatial contiguity to the design of GLAR applications can help with the management of working memory limitation and reduce cognitive load. Temporal contiguity: Similarly to Rummer and his colleagues (2011), we found no advantage of adhering to temporal contiguity when simultaneously and sequentially presenting 138 audio and visual information to students such as (1) the laser fired and explosion, (2) points received and audio alert, and, (3) level cleared notification and audio alert. Of the four principles used to design the GLAR application, students' responses indicate that they were indifferent and least effected by manipulation of the temporal principle. Findings from other studies investigating the simultaneous presentation of information using temporal contiguity also indicate ambiguity about its efficacy (Michas & Berry, 2000; Mayer & Johnson, 2008). Therefore, more research is needed to understand when and how temporal contiguity is best used when designing GLAR applications. Although Mayer and other researchers provide extensive research on the importance of using the four design principles studied herein to reduce cognitive load, this study found that all of Mayer's principle claims may not hold when considering the design of tablet-based GLAR applications for our specialized population. Specifically, further research is needed to support the claim that coherence and temporal contiguity reduce cognitive load and increase GLAR performance. Also, for this study, students' comprehension of learning content

was not assessed; therefore, **no conclusions can be drawn as to whether**

high adherence to CTML principles will have an effect on content-based learning gains. 4.10.4 Implications This research is crucial for understanding how adherence to CTML principle can affect students' cognitive load and game performance when using tablet based GLAR application. To the

best of our knowledge, this work is the first to

apply CTML's principles (original designed and tested for 2D multimedia learning applications) to the design of tablet-based augmented reality applications. Thus, this work contributes the body of literature by providing a starting point for other researchers interested in designing education-based GLAR applications. In fact, most 139 educational research studies to date on educational AR applications have lacked a theoretical basis. This work further provides evidence that CTML may be an appropriate framework to ground and guide the development of GLAR applications that aim to reduce students' cognitive load. This study also suggests adhering to the principles of CTML may allow student to engage in effective cognitive processing which in turn improved their GLAR performance. 4.10.5 Assumptions and Limitations There were a few assumptions made in this study. We assumed that all participants had the same mathematics background knowledge which may not be accurate. In all likelihood, within and between groups, all participants had varying levels of knowledge because they had different mathematics teachers and came from different schools. Another assumption made was that fifth-grade participants have the ability to self-report the amount of cognitive load experienced during the gamified AR activity. To support this assumption, it should be noted that researchers Gopher and

Braune (1984) claim that elementary students are more than capable at providing a numerical value to assess their perceived stress, frustration and cognitive load. Lastly, we assumed that the degree in which we manipulated the principles of CTML between GLAR adherence interfaces was sufficient enough to determine differences in GLAR performance and cognitive load among the students. Results suggest that the low, and medium adherence interface conditions did indeed effect cognitive load and GLAR performance. A limitation of this study is the potential for participants' preferred cognitive style to be unmatched (or matched) by Celestial Blast interface design. This individual factor could have had an impact on students' actual cognitive load, and thus self-reported cognitive load scores. Another limitation of the study was ensuring participants were fully engaged during the three gamified AR sessions. To overcome this limitation, at the start of each session, researchers encouraged participants to achieve the highest possible score amongst all other participants. Participants with the highest scores were acknowledged and awarded with pancakes, while all other participants received Skittles candy.

More research is needed to determine **the** appropriate **time** in **which** students should **be** exposure **to**

GLAR adherence interfaces before fatigue or distraction effects occur. In this study, four principles of CTML were manipulated collectively rather than individually. Therefore, we cannot determine which particular principle(s) had the greatest impact on cognitive load and GLAR game performance (although the user satisfaction survey provides some insights). More

research is needed to investigate the individual principles **of** CTML **in** gamified **AR**

settings. Also, the user satisfaction survey data was not formally nor fully analyzed. Therefore, future research should examine this data more deeply, by for example, performing a cluster analysis to determine internal consistency amongst the individual principles. Another future analysis could be to perform an analysis of variance on survey response data to analyze differences among the principles. There were limitations concerning the small sample size of twenty-two participants,

which has clear ramifications for the generalizability of the study

to larger populations. However, the results can be generalized to fifth grade students who live in lower socioeconomic settings and attend Title I schools in Virginia. Students' exposure time to the GLAR interfaces is another limitation of this study. Allowing students more time to interact with the different interfaces of Celestial Blast could possibly result in different cognitive load and game performance results. Lastly, the sample of participants was not fully random due to the need to gain access to a specialized population. This lack of random sample could impact the study by (1) lowering the level of generalization of research findings, and, (2) it is difficult to estimate sampling variability as well as (3) how your study represents the entire population. 5 Impact of Cognitive Styles on Cognitive Load 5.1 Introduction Recently there has been an increase in the introduction of technological innovations in everyday life. With the evolution and advancement of these technologies, it is important for researchers, especially in the educational field, to investigate how to effectively use them for educational enhancement. Studies already report that emerging technologies are changing the way students engage and learn both in and outside of the classroom (Zimmerman, 2007; Song & Keller, 2001; Martin et al., 2011). One such emerging learning technology is augmented reality (AR) and according to the Horizon Report it has the potential to significantly impact learning (Johnson et al., 2010). Although many benefits of AR have been reported such as increased collaborations and motivation (Kaufmann & Schmalstieg, 2003; Liu et al., 2009), improvements in kinesthetic learning (Feng et al., 2008; Kortranza et al., 2009), increased spatial abilities (Arvanitis et al., 2007; Martin-Gutierrez et al., 2010),

further research is needed to fully **understand the cognitive** effects AR interfaces **and**

experiences may have on students. To understanding cognitive effects, we can begin by examining the numerous individual differences amongst students using different AR interface designs. Researchers, such as Johri and Olds (2011), have suggest that learning environments enhanced by technology can be improved by understanding and designing to individual differences. Individual differences should be taken into account when considering factors that affect learning and ways learning can be maximized. Messick (1976) believed education should capitalize on individual differences in order to promote greater learning achievements. Therefore, the literature suggests that researchers can better understand individual differences and account for such differences amongst students using cognitive styles (D'Mello, Craig, Fike, & Graesser, 2009). Cognitive style is defined by Messick (1976) as consistent individual differences in which students prefer to perceive, organize and process information. Messick further purports that the influence of cognitive styles extends to almost all human activities that involve cognition. Ehrman (1999) suggests that knowledge about students' cognitive styles will enable researchers and educators to better understand students' stages of cognition and the psychological effects students may experience when using AR. Further, researchers have determined that cognitive style is a factor that affects a number of areas in the classroom such as the way teachers teach, the way students learn, students' preferences and students' academic achievement (Clark, 1971; Witkin, Lewis, & Weil, 1968; Oltman, Goodenough, Witkin & Freeman, 1974). According to Cakan (2006), delivering content in a manner consistent with students' cognitive style is one of the most significant factors that may impact students' learning outcomes because it allows students to make sense of the classroom environment by collecting, analyzing, evaluating, and interpreting data. Knowledge of cognitive styles may not only be valuable in determining the most effective teaching and learning methods, but also how to properly design technology-based learning applications. According to Refsgaard and Henriksen (2004), it is also valuable in developing guidelines that effectively present information to students while accounting for their cognitive differences (Refsgaard & Henriksen, 2004). In order to maximize students' cognitive outcomes and design effective AR learning applications, researchers and developers should adopt established cognitive theory in order to account for students' cognitive styles and to structure the presentation of information. One such theory that can inform design

based on the cognitive resources **of** students is **Mayer'** s **Cognitive Theory of Multimedia Learning**

(CTML) (Moreno, 2004). CTML provides principles that account for students' cognitive differences and processes and when used in multimedia learning design, results in systems that empower students to actively process and organize information held in working memory.

However, little research has been conducted on accounting for individual cognitive

differences when applying principles of CTML. It is important to investigate whether certain design principles of CTML correlate to a certain cognitive style (e.g., field-independent students) better than other design principles.

More research is needed to investigate the relationship between students' cognitive style differences and presentation of information to

ensure that emerging technology interfaces do not overwhelm students. Therefore, this study will investigate how students' cognitive style can inform the design of AR learning interfaces with the goal of improving students' cognitive performance. 5.2

Purpose of the Study The objective of this research is to establish if there

is a relationship between students' cognitive style and cognitive load when designing a gamified learning AR (GLAR) application. Specifically, this study investigates how accounting for individual differences using cognitive style influence cognitive load and the creation of new knowledge when using a GLAR application. Cognitive style is

an important factor to consider when designing GLAR because it is the

manner in which students perceive, organize and process information (Price, 2004). The research will develop an understanding on how certain principles of CTML effects the way students perceive and process information based on their cognitive style; examining both field-dependent and field- independent cognitive styles. This research will further analyze cognitive load, content-based learning gains and game performance to examine to what degree CTML principles map to a particular cognitive style. Specifically, this research will systematically vary both the voice and 145 coherence principles of CTML, using four GLAR interfaces to

determine if differences exist between field-independent (FID) and field-dependent

(FD) students' cognitive outcomes (and in turn inferring to what degree these principles support students' cognitive needs). This research proposes that the consideration of cognitive styles might provide researchers with GLAR design insight to help minimize the cognitive load of students interacting with such GLAR applications. The results of this study will determine if cognitive styles are an important consideration when designing GLAR applications. Additionally, the

research will add to the existing literature by establishing guidelines on how to reduce cognitive load in GLAR applications while accounting for individual differences. 5.3 Related Works An important focus of psychological research into student learning concerns the cognitive aspects of learning. The study of cognitive styles is an area of research that supports the psychological implications on students. Early researcher that understand students' abilities to form concepts, solve problems and build mental models led to interest and research in students' cognitive styles. Numerous definitions of cognitive style are available, but to guide this research we define cognitive style as the ways in which a student conceptually organizes and process information in the environment based on their perceptual and intellectual abilities (Merriam & Caffarella, 1991).

To understand cognitive styles and their educational significance, Witkin

et al. (1977) began to investigate the impacts on cognition by identifying the complementary cognitive styles termed field dependence and field independence; two of the most commonly cited cognitive styles in the scientific literature. The key difference between FD and FID students is the way in which they process visual information (Riding & Cheema, 1991). According to Witkin (1977), FD

students may need more specific instructions **in** “problem solving strategies” **or** a clear **definition of** learning objectives and **performance outcomes**

as compared to FID

students who may perform better when allowed to develop their own strategies

(Witkin, 1977). In 1971, Grieve and Davis investigated the role of cognitive style on two different methods of instruction (i.e., expository and discovery) with ninth grade geography students. The research concluded that FD students had significant difficulty in acquiring knowledge of Japan’s geography and had difficulty applying the information to new situations. However, FID students have the ability to organize and apply the information to new situations on their own (Grieve & Davis, 1971). Messick (1976) points out that FID students can easily differentiate objects from embedding contexts, and have more facility with tasks requiring differentiation, whereas FD students tend to experience events globally in an undifferentiated fashion. Lastly, FD students have a great connection to social orientations such as conversations with other students to understand the information presented while FID students prefer to work alone to distinguish concrete information from complex perceptual fields. Such results were bolstered by a study conducted by Fitzgibbons and Goldberger (1971) which investigated the relationship between cognitive style and memory recall. The study found that FD students can more easily recall material of a social nature or related to social interactions verses FID students whom more easily recall information that is task related (Fitzgibbons & Goldberger, 1971). Essentially, FID students are not distracted by irrelevant information and can acknowledge important visual information easily. While FD students can be distracted by irrelevant information, thrive on social interactions and benefit from visual cues to help identify important information. Research by Lin and other researchers have shown that cognitive style is the best individual factor to consider when developing interfaces and assessing the role of individual differences in student learning outcomes (Lin, Huang, & Kuo, 2009). A study conducted by Parcels (2008) found that designing online instructions to match the cognitive style of FD students resulted in increased performance on pre- and post- assessments. According to Parcels (2008), understanding students' cognitive style and designing online instructions to meet individual cognitive needs has a positive impact on achievement for both FD and FID students. However, a study conducted by Hall (2000) found that interactive treatments provided by a computer program to support cognitive styles did not improve the performance of FD students. His research presented geography students jigsaw puzzle that was created using a computer program. The jigsaw puzzle was made from maps and "randomly varied the type of interactivity available to students when solving the puzzles." He hypothesized that FD students would solve the puzzles quicker with more accuracy when they interacted with the jigsaw puzzle. However, FID students were faster (Hall, 2000). Ogle (2002) conducted a study to investigate how students' cognitive style affects learning outcomes in a virtual environment. His research also found

that there were no significant **differences in** test **scores for participants who**

received information virtually versus non-virtually. However, there was a significant interaction effect for FID students who received information in a virtual environment. Overall,

this study concluded **that virtual environments** had **no effect on the recall ability of**

FD students and a positive effect for FID students. The aforementioned studies establish how students' differences can affect

learning; however, more research is needed that addresses how **to** specifically meet **the** needs **of**

FD students. Also, research that examines the role of cognitive styles when using AR applications is missing in current literature (Chen & Tsai, 2012). 5.3.1 CTML design principles Research shows that technology can achieve significant learning outcomes when it is explicitly

designed to take the student **and human cognitive** limitations **into consideration**

(Paas, Renkl, & Sweller, 2003; Clark, Nguyen, & Sweller, 2005; Sweller, 2005). CTML provides principles to help guide the design of technology such as AR to account for the cognitive differences amongst students. Researchers believe the voice and coherence principles of CTML can help respond to students' cognitive processing and meet the needs of both FD and FID students. The objective of the coherence principle is to reduce extraneous load by eliminating irrelevant visual and auditory information (Mayer, 2005). According to Clark and Mayer, this is the single most important principle as cautious selection of visual and auditory information is needed to ensure maximum learning outcomes. Most studies that examine the coherence principle

have reported that the inclusion of extraneous information hinders **learning** for all students **(Bryant, 2010; Lehman et al., 2007; Lusk, 2008; Mayer et al., 2008; McCrudden & Corkill, 2010; Rowland et al., 2008;**

Rowland-Bryant et al., 2009; Verkoeijen & Tabbers, 2009).

The objective of the voice principle is to help with the processing of information by embedding social-motivational cues in instructions (Mayer, 2009). According to Mayer, all students specially FD students perform better on problem solving transfer tasks and increase their understanding of the learning content when audio is delivered by human voices instead of simulated voices.

Studies have further **found that** voice alone **has a significant impact on learning for**

all students and removal of social cues results in negative effects on learning outcomes especially in FD students (Lin et al., 2016; Mayer, 2009; Mayer et al., 2003; Ahn, 2010). 5.3.2 Supporting Field Dependent Students Field dependence is a mode of perceiving the environment wherein one's perception is controlled by their surrounding and whereby the surrounding parts are undetectable. When a person is FD, they have a global approach to problems and have difficulty disembodying parts and imposing structure on an ambiguous situation (Witkin et al., 1977). Since a FD student may have difficulty for example, distinguish objects from their backgrounds, they often require more "explicit instruction in problem solving strategies" (p. 25). FD students are oriented more towards social activities and prefer to participate in collaborative activities. They learn material with social context and seek externally defined goals and reinforcement. Although their approach to learning is passive, they constantly monitor and respond to their authentic environment by utilizing their senses to process information. They also use existing organization of material to help when cognitively processing new information. Therefore, the coherence principle will be leveraged to take a minimalist approach to GLAR design, providing well-defined goals and include necessary information needed to understand learning content being presented. Since stress tends to impair memory in FD students, the GLAR applications should provide students with a clear and straightforward application that reduces ambiguity but also ensures the learning content is not repressed. By limiting the amount of information presented to FD students, GLAR applications may reduce students' stress while improving their critical thinking skills and ability to work. The voice principle will provide FD students with social cues, aural alerts and positive feedback to increase social connectedness. Using conversational feedback and creating a social presence within GLAR may help students relate to learning content and increase students' ability to transfer knowledge from the GLAR application to a new task. 150 5.3.3 Supporting Field Independent Students Field independence is a mode of perception where an individual experiences new environments in discrete parts rather than a continuous whole (Anderson, 1988). A person who is FID can distinguish concrete information from its context and takes a self-directed approach to learning. According to Witkin et al. (1977), FID students prefer to work alone in solitary learning activities and exhibit greater skill in organizing information in working memory. Superior cognitive restructuring ability appears to enhance the student's ability to learn the content while working alone. These students perceive information analytically and can find organization in an unstructured environment while using an active approach to learning. They learn more in the absence of external reward and when intrinsic motivation is present. FID students are less susceptible to interferences from outside influences and can navigate through non-salient information in order to determine relevant information. Although stress has less effect on FID students' cognition, it is still important to utilize appropriate design principles to manage students' cognitive load. For FID students, the GLAR application leverages voice and text to present information using dual channels. According to Mayer, students learn more when information is conveyed using audio and visual rather than visual presentation alone. By including auditory cues, FID students will have the opportunity to construct new mental models that include

new knowledge and information already present **in** their **long-term memory** (which **in**

turn deepens contextual learning). However, the aural cues will not include voice-based positive feedback as described above for field-dependent students. Positive feedback could be considered bothersome for FID students and hinder contextual learning. The coherence principle is used to present FID students information in a top down, logical order. Although FID students can distinguish between relevant and non-relevant information, it is easier and quickly for 151 them to process an abundant amount of information when they can encode the information with existing knowledge to give it meaning. Thus, GLAR applications should adequately challenge students by presenting them with relevant but abstract information while also using dual channel modality. 5.4 Research Questions Research Question 1: Is the cognitive load of field-independent and field-dependent students impacted when voice and coherence principles of CTML are manipulated in GLAR application "Build-A-World"? Hypothesis (H1): The cognitive load of field-dependent students is significantly lower in the VonChigh condition relative to the other conditions when voice and coherence principles of CTML are manipulated in "Build-A-World". Hypothesis (H2): Field-independent students' cognitive load remains constant across the four experimental design conditions when the voice and coherence principles of CTML are manipulated. Research Question 2: Does students' cognitive style impact GLAR performance when voice and coherence principles of CTML are manipulated in GLAR application "Build-A-World"? Hypothesis (H3):

Field-dependent students perform significantly higher **relative to field- independent students**

when the experimental condition of the coherence principle is high in the GLAR application "Build-A-World". Hypothesis (H4): Field-independent students' GLAR performance improves when the experimental condition of the voice principle is off in the GLAR application "Build- A-World". Research Question 3: Are there content-based learning gains for field-independent and field-dependent students after engagement with GLAR application "Build-A- World"? Hypothesis (H5): There are content-based learning gains for both field-independent and field-dependent students after engagement with "Build-A-World". Hypothesis (H6): The content-based learning gains is significantly higher for field- dependent students relative to field-independent students after engagement with "Build-A-World". 5.5 Study Overview This study is a

2 x 2 x 2 mixed factor experimental **design** with **three independent variables:**

voice principle (on, off) within subjects, coherence principles (low, high) within subjects and cognitive style of the participant (FID, FD) between subjects. This research design aims to investigate the impacts of FID and FD cognitive styles on participants' cognitive performance when the voice and coherence principles of CTML are manipulated in a GLAR application. 5.6 Experimental Testbed: Build-A-World. A Gamified Learning AR Application For this work, we designed and built an AR application as a research testbed that afforded the research team the ability to manipulate the voice and coherence principles of CTML in a gamified AR educational setting. Build-A-World is an interactive, handheld, tablet-based AR application developed to reinforce the mathematical concepts of area, perimeter and volume to sixth grade participants. This GLAR application is designed to be used as a supplemental tool to complementary educational approaches whereby students can strengthen their existing mental models. Unlike other AR applications that require participants to wear head-mounted displays or use spatial projectors, Build-A-World was developed in the COGENT Lab

at Virginia Polytechnic Institute and State University by five undergraduate **Computer Science**

students using Unity and the AR ToolKit library. To deploy the Build-A-World requires an Android tablet to render the virtual content and a printed AR marker to position the virtual information into the real-world scene. An AR marker is a printed pattern or picture that contains a pre-programmed visual pattern that the front-facing tablet camera can recognize and use to determine the tablet's position and pose. For this application, there are five markers: four stationary and one moveable allowing the participants to view the virtual objects from different angles (Hubbard, 2009). The learning content used to inform the design of Build-A-World came from the Virginia Department of Education curriculum. The gamified AR application addressed three specific learning aims adopted from Virginia Public Schools' Standard of Learning. Aim one suggests that participants must calculate the perimeter, area and volume in standard units of measurement. The second aim was for participants to differentiate among perimeter, area and volume for a given scenario. The final aim was for participants to

identify whether the application of the concept of perimeter, area or volume is appropriate for a given situation.

Build-A-World was designed by leveraging principles of gamification and CTML (described in Sections 2.1.1 and 5.3.1, respectively). The interface is composed of five gamification elements: feedback, score, narration, rewards, and freedom to fail. Each element is implemented to help engage participants succeed in the activity by directing their attention to important content. Based on CTML, the application utilizes dual channels of modality to allow for 154 both visual and auditory processing. Also, auditory and visual information is presented simultaneously to reduce their cognitive load when interacting with the application. The coherence principle of CTML ensures that only relevant information related to area, perimeter and volume are presented to participants which helps ensure that participants' working memory resources are managed efficiently. The voice principle of CTML is leveraged but using a human voice to deliver auditory alerts and messages to help develop social connectedness with participants. Social connectedness is defined as a cognitive representation of the degree participants feel connected to other participants or social interactions (Lee & Robbins, 1995). Build-A-World, as shown in figure 18, was designed around a sci-fi gamification theme whereby aliens from the outer reaches of space where traveling to Mars to visit their Martians friends. However, to support the visit, the Martians have to first build a place for the aliens to land their UFOs. Participants have to help the Martians build a landing strip with a defined perimeter so the Aliens can safely land their UFOs. The participants have 15 minutes to build the landing strip with the accurate perimeter. The design mission allows participants to use their creativity and apply their content knowledge to accomplish the task. Figure 17: Build-A-World Interface Build-A-World initially provides participants with a limited amount of material to build the landing strip. There are four materials the participants can use to build their landing strip: steel, wood, crystal and brick. To play the game, participants first select which material they want to use then double tap anywhere on the tablet surface in the location where they want the material block to be placed. Each material block is 1 x 1 x 1 unit in size and can be placed side by side or stacked on top of each other in all three dimensions. As participants build the landing strip, they place virtual material blocks

into the real **-world (e.g.,** on **the** table **in the** classroom), **and**

can view their 3D designs from arbitrary locations by walking and pointing the tablet back toward the fixed printed marker (where their virtual design is displayed). To acquire more material, participants visit the markets by first walking to one of four room locations (corresponding to each material market) where printed markers have been mounted to the wall. Students then questions relating to the learning content that were adapted from Virginia Standard of Learning. If a question is correctly answered in the market, participants will receive a random amount of building material. However, if a question is answered incorrectly after two attempts participants will receive a new 156 question. In order to leave a market and gain additional material, the participant must correctly answer at least one question. After each visit to a market, participants may continue building their landing strip until the structure is completed. Throughout gameplay, participants can inspect the perimeter of their structure to assess the current perimeter and plan modifications needed to eventually meet the target perimeter. If they are successful at building the landing strip and have time remaining, participants have the opportunity to freely build anything they want with an unlimited amount of material. If the current perimeter does not match the target perimeter, participants must keep working on the landing strip and answering questions until the target parameter is met or the 15 minutes expire. The experimental setting and examples of participants utilizing the GLAR application are displayed in figures 19 and 20. Figure 18: Experimental Setting Figure 19: Participants utilizing Build-A-World 5.7 Independent and Dependent Variables To explore the interaction between CTML design principles and participants' cognitive style differences, four Build-A-World interface conditions were created by crossing the two conditions of the voice and coherence principles as shown in table 5. Each of the four Build-A- World conditions require participants to build a different sized landing strip. 5.7.1 Voice Principle: 2 levels (on and off), within-subjects In voice-on conditions, participants were presented aural voiceover cues such as narrations, alerts and positive feedback. The voiceovers were a male human voice used to highlight significant information and encourage participants throughout the game. For example, when UFOs were five minutes away from Mars, participants receive an auditory alert saying, "The Aliens are five minutes away! Hurry and complete the landing strip before they arrive!" At the market, participants receive positive feedback such as "Congratulations! You have answered another question correctly." The inclusion of voiceovers increases the processing of significant information for participants that interpret social communication as vital information which allows for deeper active processing of the social cue. For voice-on, the use of positive feedback and encouragement can foster a sense of connectedness with other participants and the GLAR application. Therefore, by examining voice as an independent variable we can give insights on social connectedness and how social connections effects cognitive load, GLAR performance and content-based learning gains. For voice-off conditions, all voiceover cues were removed. Removing voiceovers decreases the degree of social connection perceived by some participants and can negatively affect content-based learning gains when participants have to allocate more effort to understand significant information. 5.7.2 Coherence Principle: 2 levels (high and low), within-subjects In high-coherence condition (figure 21), a minimalistic interface was used that includes only information relevant to the mission. Thus, the high-coherence condition includes the core six pieces of information necessary for participants to complete the challenge. (1) The top of the screen displays the four types of materials as well as how many blocks are remaining for each material type. (2) Beneath the materials is the delete mode function, which allows participants to remove unwanted material blocks. (3) The mission statement is displayed beneath the materials, which informs participants of the game's objective and the target perimeter of the landing strip. The bottom of the screen displays: the timer, perimeter check and submit buttons. (4) The timer displays how much time is remaining in the mission. (5) The perimeter check button allows participants to highlight which material blocks they want to inspect the perimeter of their landing strip. (6) And finally, the submit button allows participants to calculate the perimeter of the highlighted blocks. High coherence should allow for visual perceptiveness which is defined by the ability to distinguish important parts of the interface from the complete interface or cognitive restructuring (Messick, 1993). By examining coherence as an independent variable we can give insights on visual perceptiveness. Figure 20: High Coherence Interface for Build-A-World In the low-coherence condition (figure 22), participants are exposed to nine pieces of information, six of which are the same as those presented in the high-coherence condition. The additional three pieces of information include: score, updates on incoming UFOs, and blocks placed. (7) As participants earn more points, the score is visually updated. (8) The updates on incoming UFOs are displayed on every three minutes as both an auditory and visual alert. For example, the first alert says "The Aliens have just started their journey to Mars. You have 11 minutes to finish the landing strip." (9) The blocks placed displays the total number of blocks placed in the scene at and is updated as participants add and delete material blocks. The additional pieces of information in low-coherence conditions presented participants with irrelevant information, which focuses them to utilize unnecessary cognitive resources to determine what information is important: a task that is likely harder for some participants than others. Figure 21: Low Coherence Interface for Build-A-World Table 27: The study employed four Build-A-World Interface Conditions Coherence Principle Voice Principe Low High On VonClow VonChigh Off VoffClow VoffChigh Participants were exposed to all four experimental conditions. To prevent ordering effects, exposure to conditions were randomly order per participant. According to Easterby (1984), it is important to prevent ordering effects because such effects can impact performance as well as the cognitive processes that affect comprehension. 5.7.3 Cognitive Style: 2 levels (field dependent and field independent), between-subjects Cognitive style is the way a student organize and process information that is distinct to them (Witkin et al., 1977). According to Cakan, cognitive styles is the most significant factor that may impact students' learning outcomes because it allows the student to make sense of the classroom environment by collecting, analyzing, evaluating, and interpreting data.

There are two types of cognitive style: field dependent and field independent.

Field dependent students require more organizational structure to distinguish information within a larger visual field and rely on social connectedness while field independent students are analytical and can distinguish concrete information from a larger visual field.

We used the Group Embedded Figures Test (GEFT) to determine the cognitive style of participants. The

GEFT is a twenty minute test that requires participants to locate and outline 18 simple geometric figures hidden within a drawing of a larger, more complex

geometric shape. The score of the test ranges from zero to eighteen where one point is given for each correctly outlined simple figure. If a participant scored between 2 and 10 we identified them as FD and scores from 11 to 18 allowed us to identify FID participants. 5.7.4 Dependent Variables The dependent variables of the study were cognitive load scores, results on pre-/post- assessment, learning gains, game score and percentage of correct answers. The dependent measures were collected through self-reported cognitive load surveys (NASA TLX), pre-/post- assessments and GLAR game metrics. 163 ? Pre-/Post- assessment results: pre-assessment determined the participants' level of understating of learning content before exposure to Celestial Blast. The results ranged from 0 (lowest/no questions answered correctly) to 10 (highest/all questions answered correctly). The post-assessment determined the participants' level of understanding of the learning content after exposure to Celestial Blast. The results ranged from 0 (lowest/no questions answered correctly) to 10 (highest/all questions answered correctly). ? Learning gains: these gains are calculated as the differences between pre- and post- assessment results, and ranged from -3 (worst) to 6 (best). ? GLAR game metrics: game score achieved and percentage of correct answers. Students visited the market place to gain additional material and in order to leave the market, they had to correctly answer at least one question. Percentage of correct answers

was calculated by dividing the number of total questions asked by the number of questions they correctly

answered and ranged 0 (lowest/no questions answered correctly) to 1 (highest/all questions answered correctly).

It is important to note that correctly answering questions in the

market place had no effect on the game score. ? Cognitive load scores: average workload from NASA TLX survey ranged from 0 (lowest workload) to 1 (highest workload). 5.8 Methodology 5.8.1 Participants The target population for this study will be fifth grade students from Title I schools in Virginia Public Schools. Title I is a funding program provide by the U.S. Department of Education to "assist low income and at-risk students who are struggling academically to obtain a high-quality education and reach, at minimum, proficiency on challenging state academic achievement standards and assessments." The study employed 26 participants from different Title I schools in the Southeast region of Virginia. All participants completed a public education through the fourth grade and passed necessary Virginia SOLs in order to move onto the fifth grade. Researchers gained access to the participants through the Boys and Girls Club (BGC) of Southeast Virginia. The BGC is an afterschool program that encourages children, especially those who at risk,

to realize their full potential as productive and **responsible citizens. The**

organization emphasizes "school work and offers programs on character and leadership development, the arts, health and life skills, and computer skills" while promoting a sense of competence, usefulness and belonging to the boys and girls. BGC advocates for educational advancement to prepare students for future opportunities as they work diligently to achieve their dreams (BGCA, 2012).

Participants were first **divided into two groups based on their** cognitive style (FID **and**

FD) as determined by the Group Embedded Figures Test. These two groups were further divided in half to create four groups of participants (two groups of FID, two groups of FD) to match the four interfaces conditions described in table 5. Since all 26 participants had graduated 4th grade, it was assumed that all participants had been introduced to area, perimeter and volume during grade five of their academic career and have a basic understanding of these concepts. This basic understanding allowed participants to navigate through the four interface conditions and answer questions throughout the experiment. 5.8.2

Research Setting The study was conducted at Franklin **Middle School in**

Franklin, Virginia

during the fall **semester of the** 2017-2018 **academic school year.** Inside **the**

classroom at Franklin Middle School, participants sat in the appropriate cognitive style group that was assigned (based on results of the GEFT). Each participant received their own Android tablet and marker. Participants in the FID groups worked independently while participants in the FD groups worked collaboratively to complete the Build-A-World mission. 5.8.3 Instrumentation 5.8.3.1 Group Embedded Figures Test To evaluate cognitive style, participants were given the

Group Embedded Figures Test (GEFT), developed by **Oltman, Raskin and** Witkin **(1971). GEFT is a perceptual** exercise that **requires**

subjects "to locate a simple figure embedded within a more complex geometric figure" and then trace around the located simple figure. The test is an easy instrument to administer and widely accepted as a measure of determining cognitive styles (Rusch et al., 1994). GEFT is comprised of three sections in which there are seven practice questions in section one, nine test items in section two and nine test items in section three that have a time limit. A subject’s score is based on the combined number of simple figures correctly traced within twenty minutes. The score of the test ranges from 0 to eighteen where one point is given for each correctly outlined simple figure. If a subject score between 2 and 10 they are identified as FD and scores from 11 to 18 indicate FID subjects. Results from research conducted by Witkin et al. (1977) found that GEFT is a valid and reliable method of assessing if a subject is FID or FD. Keyser and Sweetland found that "GEFT can yield data that provide insights for those engaged in cognitive style research" (p. 193). Further,

Thompson and Melancon (1987) note that the GEFT "... produces expected and **desired variations when subjects are adults rather than children" (p.**

770). However, Flexer and Roberge (1983) reported a reliability coefficient of 0.79 for performance of sixth and seventh grade participants. 5.8.3.2 Pre-/Post- Assessments In order to assess participants’ prior knowledge about area, perimeter and volume, participants were given a pre- assessment that included questions derived from previous SOL assessments. To evaluate content-based learning gains after interacting with Build-A-World, a post- assessment was also administered. Both the pre- and post- assessment had ten questions that required participants to demonstrate their ability to calculate, and differentiate amongst, area, perimeter, and volume. Although each assessment was different, both used multiple choice answer format to mimic the style of actual SOL questions. The SOL questions used were state approved and in accordance with Virginia Department of Education guidelines, meeting state educational standards. 5.8.3.3 NASA Task Load Index (TLX) NASA TLX, a commonly used instrument in many fields of human factors and related research, was used to measure cognitive load. For a detailed description, see section 3.5.5.2. 5.8.3.4 User Satisfaction Survey Similar to study two, a user satisfaction survey was used to evaluate satisfaction of Build- A-World. For more details, see section 4.7.3.2. Additionally, Appendix K, L, M, and N for the complete user satisfaction questionnaires. For this dissertation work, we did not formally assess the results via statistical analysis; however, Appendix P contains simple descriptive statistics for the complete user satisfaction questionnaire. 167 5.8.4 Data Collection Procedures This study required six separate sessions with participants at the Boys and Girls Club. During the first session, the primary researcher and GLAR designers administered the GEFT to participants per the GEFT administering guidelines. The primary researcher scored the GEFT, recorded the scores and placed the participants in their respective groups. Lastly during session one,

participants completed a pre- assessment to evaluate **their** prior **knowledge on the** learning content. During **the assessment,**

researchers gave verbal instructions and answered questions as needed. At the beginning of the second session, the research team gave a presentation to participants that outlined game instructions, how to generally use the AR tablet application, and led a two-minute interactive demonstration on how to play Build-A-

World. Sessions 2 through 5 were used to expose each of the four participant groups to each of the four interface conditions.

At the beginning of each session, participants **were randomly assigned**

an interface condition they would be interacting with

during the session. Participants were given thirty **minutes to complete the**

Build-A-World mission, during which time researchers assisted FID participants if they had any questions on the learning content or GLAR interface. For example, if a FID participant was having trouble seeing the graphics, the researcher would have instructed the participant to manipulate, rotate or move the AR marker to increase or decrease their field of view or view the structure they were building from a different perspective. FD participants were instructed to helped each other if they experienced any problems. At the conclusion of sessions two through five, each participant recorded their game score, completed a NASA TLX survey, and answered user satisfaction survey questions. The rotation of interfaces across sessions were randomized (without replacement) to mitigate possible practice and/or learning effects. In the final session, participants completed a post- assessment to assist in determining whether there were any content-based learning gains. As with the pre- assessment, the researchers gave verbal instructions and answer questions as needed. 5.9 Results 5.9.1 Research Question 1 Is the cognitive load of field-independent and field-dependent students impacted when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? 5.9.1.1 Descriptive Statistics For cognitive load, the unweighted NASA TLX scores were reported as a measure of average workload. We used the Levene Test to determine if it was appropriate to utilize ANOVA to analysis the average workload data and calculated the variability and homogeneity among the data for FID and FD students. A test of homogeneity of variances found F(3, 48) = 0.482, p = 0.093. Homogeneity has not been violated. Then, we conducted Kolmogorov-Smirnov tests to determine if the normality assumption has been violated. The

tests demonstrated the assumption **of normality** was **violated for the** VonChigh condition **(Z** = .114, **p**

= 0.061, with slight skewness to the left = -0.426, kurtosis = -0.358), the VonClow condition (Z = .190, p < 0.0001, with slight skewness to the left = -0.315, kurtosis = -0.787), the VoffChigh condition (Z = .152, p < 0.05, with slight skewness to the left = -0.202, kurtosis = -0.528), and the VoffClow condition (Z = .105, p = 0.0001, with slight skewness to the left = -0.407, kurtosis = -0.315) was not violated. Because the robust nature of ANOVA, it was utilized to analyze the non-parametric data because “the limitations associated with the violation of normality are reduced and the effect of normality upon Type I error rates is minimal because the observed skewness was not in the extremes” (Hinkle, Wiersma, & Jurs, 2003). The descriptive statistics presented in table 10 displays the means, standard deviation and standard error for average workload which was used for hypotheses testing. 1.2 1 A verage W orkload 0.8 * * * * FD M FID M 0.6 0.4 0.2 0 V(on

)C(high) V(on)C(low) V(off)C(high) V(off)C(low)

Experimental Conditions Note. Lower average workload is better Figure 22. Experimental Conditions Impact on Average Workload by Cognitive Style Table 28. Means, Standard Deviations and Standard Errors of Average Workload FID FD M SD SE M SD SE VonChigh VonClow VoffChigh VoffClow 0.238 0.289 0.279 0.284 0.177 0.142 0.136 0.128 0.050 0.039 0.037 0.036 0.229 0.471 0.528 0.708 0.201 0.168 0.160 0.194 0.056 0.047 0.044 0.053 5.9.1.2 Hypothesis Testing The analysis of cognitive load

utilized a 2 x 2 x 2 mixed method Analysis of Variance (ANOVA) to

address research question 1 and test specific hypotheses relating to research question 1. This ANOVA model contained two within-subject factors: Voice (on, off), and Coherence (high, low).

Levels of the within -subjects factors are crossed with one another as shown in table

5. There was one between-subjects factor: Cognitive Style (FD and FID). The

results of the ANOVA for the average workload are displayed in table

12. We found main effects of cognitive style (F (1,1) = 42.514; p = < 0.0001), voice principle (F (1,1) = 19.487;

p = < 0.0001) and coherence principle (F (1, 1) = 13. 636; p = 0.

0004) on average workload. There was a two-way interaction effect of cognitive style by voice (F (1,1) = 14.753; p = 0.0002) and cognitive style by coherence (F (1,1) = 7.967; p = 0.0058) on average workload; however, we found no interaction effect of voice by on average workload (F (1,1) = 0.681; p = 0.411). Table 29. ANOVA Results for Fixed Effects of Average Workload Average Workload Source Cognitive Style Voice Coherence Cognitive Style x Voice Cognitive Style x Coherence Voice x Coherence Cognitive Style x Voice x Coherence F 42.514 19.487 133.6359 14.753 7.9674 0.6815 0.0129 p < .0001* < .0001* 0.0004* 0.0002* 0.0058* 0.4111 0.9097 Hypothesis (H1): The cognitive load of field-dependent students is significantly lower in the VonChigh condition relative to the other conditions when voice and coherence principles of CTML are manipulated in “Build-A-World”. To address hypothesis 1, we conducted a post-hoc analysis to find differences between FD students across the experimental conditions. The Tukey HSD post-hoc analysis (table 30) showed that FD students had significant differences across the experimental conditions and average workload

was significantly lower for FD students in the VonChigh condition as compared to

all other voice and coherence conditions. The effect size was calculated using the formula: d = μ1− μ2. According to $\sigma oooldd$ Cohen (1998), the effect size is considered large when it is more than 0.8, median is between 0.5 and 0.8, small is between 0.5 and 0.2 and there is no effect when it is less than 0.2. The effect size for the post-hoc analysis is included in Table 30. Therefore, we can accept the hypothesis 1 and assume that the cognitive load of FID students is significant lower in the VonChigh condition relative to the other conditions when voice and coherence principles of CTML are manipulated. Table 30. Tukey HSD post-hoc analysis of Cognitive Style across experimental conditions Cognitive Style Comparisons Difference Std Err p d FD VoffClow VoffChigh VonClow VoffClow VoffClow VoffChigh VonChigh VonChigh VonChigh VonClow VoffChigh VonClow 0.478846 0.298077 0.241667 0.23718 0.180769 0.05641 0.064837 0.064837 0.064837 0.064837 0.064837 0.064837 < 0.0001* 0.0003* 0.0076* 0.0095* 0.1102 0.988 2.89678 1.80322 1.46196 1.43482 1.09356 0.34125 FID VonClow VoffClow VoffChigh VonClow VoffClow VonClow VonChigh VonChigh VonChigh VoffChigh VoffChigh VoffClow 0.051282 0.046795 0.041667 0.009615 0.005128 0.004487 0.064837 0.064837 0.064837 0.064837 0.064837 0.064837 0.9932 0.9961 0.9981 1 1 1 0.31023 0.28309 0.25206 0.05817 0.03102 0.02715 Hypothesis (H2): Field-independent students’ cognitive load remains constant across the four conditions where voice and coherence principles of CTML are manipulated. To address hypothesis 2, a Tukey HSD

was conducted to compare the cognitive **load of** FID **students** across **the**

experimental conditions. The Tukey HSD post-hoc analysis showed no significant different in average workload across experimental conditions for FID students. Therefore, we can accept hypothesis 2 and assume that cognitive load remained constant for field-independent students across all conditions where voice and coherence principles of CTML were manipulated. 5.9.2 Research Question 2 Does students’ cognitive style impact GLAR performance when voice and coherence principles of CTML are manipulated in GLAR application “Build-A-World”? 5.9.2.1 Descriptive Statistics Game scores and percentage of correct answers

(proportion of correct answers to the total number of questions asked **in the**

market place) were reported as a measure of GLAR performance. First, we tested the assumption of homogeneity of variances using the Levene statistic, F(1, 26) =1.026, p = 0.039. This assumption has not been violated. Next, we conducted Kolmogorov- Smirnov Tests to determine normality of game scores and percentage of correct answers data. For the Von condition (Z = .065, p = 0.200, with slight skewness to the left = -0.591, kurtosis = -0.223), the Voff condition (Z = .190, p < 0.0001, with slight skewness to the left = -0.513, kurtosis = - 0.215), the Chigh condition (Z = .152, p = 0.093, with slight skewness to the left = -0.178, kurtosis = -0.822), and the Clow condition (Z = .105, p = 0.002, with slight skewness to the left = -0.421, kurtosis = -0.926). Although Von condition violated normality, ANOVA was utilized to analyze the non-parametric data because “the limitations associated with the violation of normality are reduced due to the robust nature of ANOVA and the effect of normality upon Type I error rates is minimal because the observed skewness was not in the extremes” (Hinkle, Wiersma, & Jurs, 173 2003). Table 13 displays the means, standard deviation and standard error for game score and

table 14 displays **the means, standard deviation and** standard error **for** unweighted percentage **of**

correct answers, which were used for hypotheses testing. Figure 23. Game Score for Coherence Principle by Cognitive Styles Figure 25. Game Score for Voice Principle by Cognitive Styles Table 31. Means, Standard Deviations and Standard Errors of Game Score FID FD M SD SE M SD SE Von Voff Chigh Clow 3234.62

2598.08 2782.69 3050 2012.35 1609.56 1619.379 2047.29 394.65 315.66 317.59 401.51 4242.31 2257.69 3111.54 3388.46 2007.52 836.38 1769.71 1898.96 393.71 164.02 347.07 372.42 Figure 24. Percentage of Correct Answers for Coherence Principle by Cognitive Styles Figure 25. Percentage of Correct Answers for Voice Principle by Cognitive Styles Table 32. Means, Standard Deviations and Standard Errors of Percentage of Correct Answers FID FD M SD SE M SD SE Von Voff Chigh Clow 0.794 0.749 0.801 0.742 0.238 0.259 0.224 0.270 0.047 0.050 0.044 0.052 0.647 0.552 0.687 0.511 0.242 0.263 0.259 0.222 0.047 0.052 0.051 0.043 5.9.2.2 Hypothesis Testing Two 2 x 2 x 2 mixed method ANOVAs were conducted to compare means of percentage of correct answers and game scores from FID and FD students across voice and coherence conditions. These ANOVAs addresses research question 2 and tested specific hypotheses relating to research question 2. The

results of the ANOVA for the game score **are** displayed **in table**

15. We found no effects of cognitive style (F (1,1) = 1.0138; p = 0.3165) and coherence principle (F (1,1) = 0.6743; p = 0.4136) on game score.

There was a main effect for voice principle **(F (1,** 1) = 15.6415; **p = 0.0001)**

on game score. We found interaction effects of cognitive style by voice (F (1,1) = 4.1374; p = 0.0447) on game score; however, there were no effects of cognitive style by coherence (F (1,1) = 0.0002; p = 0.4136), or voice by coherence (F (1,1) = 2.7259; p = 0.1020) on game score. The effect size for the voice principle d = 0.6423 and the two-way interaction of cognitive style by voice d = 0.1699. The results of the ANOVA for the percentage of correct answers are also displayed in table 15.

We found a main effect of cognitive style **(F (1,** 1) = 12.7979; **p = 0.**

0005) and coherence principle (F (1,1) = 5.8765; p = 0.0172) on percentage of correct answers.

There was no effect for voice principle **(F (1,** 1) = **2.** 1050; **p**

= 0.1501) on percentage of correct answers. We found no effects of cognitive style by voice (F (1,1) = 0.2693; p = 0.6050), cognitive style by coherence (F (1,1) = 1.4844; p = 0.2261), and voice by coherence (F (1,1) = 0.3248; p = 0.5701) on percentage of correct answers. The effect size for the coherence principle d = 0.353 and cognitive style d = 0.553. Table 33. ANOVA Results for Fixed Effects of Game Score and Percentage of Correct Answers Game Score Percentage of Correct Answers Source F p F p Cognitive Style Voice Coherence Cognitive Style x Voice Cognitive Style x Coherence Voice x Coherence Cognitive Style x Voice x Coherence 1.0138 15.6415 0.6743 4.1374 0.0002 2.7259 0.1580 0.3165 0.0001* 0.0447* 0.4136 0.9885 0.1020 0.6919 12.7979 2.1050 5.8765 0.2693 1.4844 0.3248 0.2903 0.0005* 0.1501 0.0172* 0.6050 0.2261 0.5701 0.5913 Hypothesis (H3):

Field-dependent students perform significantly higher **relative to field- independent students**

when the experimental condition of the coherence principle is high in the GLAR application “Build-A-World”. A Tukey HSD post-hoc analysis was conducted to test hypothesis 3 and find differences between students across the coherence condition. The analysis showed that FD students had statistically higher percentage of correct answers when the experimental condition of coherence was low; however, there were no statistical differences in game scores or percentage of correct answers when coherence is high. We can reject hypothesis 3 and assume that FD students did not perform significant higher relative to FID students when the experimental condition of the coherence principle was high in the GLAR application. Table 34. Tukey HSD post-hoc analysis of Coherence Principle for Game Score and Percentage of Correct Answers Measure Comparisons Difference Std Err p-Value d Game Score FD Clow FD Clow FD Chigh FD Chigh FID Chigh FID Clow FID Chigh FID Clow 605.769 338.462 328.846 61.538 468.6386 468.6386 468.6386 468.6386 0.5699 0.8880 0.8962 0.9992 0.35851 0.20031 0.19462 0.03642 % of Correct Answers FID Chigh FID Clow FID Chigh FID Clow FD Clow FD Clow FD Chigh FD Chigh 0.2426385 0.1976692 0.1475846 0.1026154 0.0682424 0.0682424 0.0682424 0.0682424 0.0032* 0.0238* 0.1412 0.4393 0.98613 0.80337 0.59981 0.41705 Hypothesis (H4): Field-independent students’ GLAR performance improves when the experimental condition of the voice principle is off in the GLAR application “Build-A-World”. To address hypothesis 4, a Tukey HSD was conducted to compare the game scores and percentage of correct answers of FID students across the voice conditions. A Tukey HSD post-hoc 179 analysis showed that FID students had statistically higher percentage of correct answers when the voice principle was off; however, there was no statistically difference between game scores when the voice principle was off. We can reject hypothesis 4 and assume that FID students did not perform significant higher relative to FD students when the voice principle was off in the GLAR application. Table 35. Tukey HSD post-hoc analysis of Voice Principle for Game Score and Percentage of Correct Answers Measure Comparisons Difference Std Err p d Game Score FD Von FD Von FID Von FID Voff FID Voff FID Von FD Voff FD Voff 1644.231 1007.692 976.923 340.385 468.6386 468.6386 468.6386 468.6386 0.0038* 0.1449 0.1655 0.8863 0.97309 0.59637 0.57816 0.20145 % of Correct Answers FID Von FID Voff FID Von FID Voff FD Voff FD Voff FD Von FD Von 0.2426385 0.1976692 0.1475846 0.1026154 0.0682424 0.0682424 0.0682424 0.0682424 0.0032* 0.0238* 0.1412 0.4393 0.98613 0.80337 0.59981 0.41705 5.9.3 Research Question 3 Are there content-based learning gains for field-independent and field-dependent students after engagement with GLAR application “Build-A-World”? 5.9.3.1 Descriptive Statistics Content-based learning gains were assessed using the dependent measures of (1) pre- assessment results, and, (2) post-assessment results. Descriptive statistics for FID and FD students across pre- and post- assessments are summarized in table 38 and 39. That data shows FID students had a median pre-assessment score of 7, with minimum and maximum pre-assessment scores of 3 and 10 respectively; and median post-assessment score of 9, with minimum and maximum post- assessment scores of 7 and 10 respectively. While FD students had a median pre-assessment score of 4, with minimum and maximum pre-assessment scores of 1 and 9 respectively; and median post-assessment score of 7, with minimum and maximum post-assessment scores of 3 and 9 respectively. Figure 26. Comparing Pre- and Post-Assessment by Cognitive Style Table 36. Descriptive Data for Pre-Assessment by Cognitive Style Percentile Cognitive Style M SD n Min Max 25 50 75 Field Dependent 4.384 2.103 13 1 9 3 4 5

Field Independent 6.846 1.951 13 3 10 5 7 8 Note. The maximum possible score was 10. Table 37. Descriptive Data for Post-Assessment by Cognitive Style Percentile Cognitive Style M SD n Min Max 25 50 75 Field Dependent 6.923 1.498 13 3 9 6 7 8 Field Independent 8.692 1.031 13 7 10 8 9 9.5 Note. The maximum possible score was 10. 5.9.3.2 Hypothesis Testing Hypothesis (H5): There are content-based learning gains for both field-independent and field- dependent students after engagement with “Build-A-World”. Two Wilcoxon Signed-ranked tests were conducted to evaluate hypothesis 5 and

determine if there were significant differences between pre- and post- assessments **for** FID and FD **students.**

For FID students, the Wilcoxon Signed-rank test indicated significant

difference between the pre- (Mdn = 7) **and post-** assessment (Mdn = 9) **scores,** Z = **3.** 41, **p**

= 0.0054. With the Z score an effect size was calculated using the formula: r = Z ,

where n is the total number of samples. **The** Wilcoxon $\sqrt{n}$ effect size **is**

considered large when it is more than 0.5, median when it is between 0.3 and 0.5, and small when it is less than 0.3 (Grissom & Kim, 2012). Therefore, the effect size of the pre- and post- assessment was r = .946. For FD students, the Wilcoxon Signed-rank test indicated significant

difference between the pre- (Mdn = 4) **and post-** assessment (Mdn = 7) **scores,** Z = **3.** 76, **p**

= 0.0034 with an effect size of r = 1.042. We can accept hypothesis 5 and assume that there are content-based learning gains for both FD and FID students after engagement with “Build-A- World”. Table 38. Field-Independent Students’ Wilcoxon Signed-rank Test Results FID Post-Assessment – FID Pre-Assessment Z 3.411 p 0.0054* Table 39. Field-Dependent Students’ Wilcoxon Signed-rank Test Results FD Post-Assessment – FD Pre-Assessment Z 3.756 p 0.0034* Hypothesis (H6): The content-based learning gains are significantly higher for field-dependent students relative to field-independent students after engagement with “Build-A-World”. Content-based learning gains were quantified using the

difference score that **was calculated as the difference between the** pre-assessment **and** post-assessment **scores.** Descriptive statistics for **difference score**

between FID and FD students are summarized in table 42. That data shows FID students had a median difference score of 2, with

minimum and maximum difference scores of -1 **and** 6 **respectively** and FD students **had a** median **difference score of**

3, with

minimum and maximum difference scores of -2 and 5 **respectively.**

Figure 27. Assessment of Learning Gains by Cognitive Style Table 40. Descriptive Data for Assessment of Learning Gains by Cognitive Style Percentile Cognitive Style M SD n Min Max 25 50 75 Field Dependent 2.528 2.436 13 -2 5 1 3 4.5 Field Independent 1.846 1.951 13 -1 6 0.5 2 3

A Kruskal-Wallis test was conducted to evaluate differences between

FID and FD students to median change in content-based learning gains differences. The test was not significant; therefore, we reject the hypotheses and assume that the content-based learning gains for FD and FID students are relatively the same. The test revealed an effect size of r = 0.239. Table 41. Learning Gains Kruskal-Wallis Test Result n Chi-square df p-Value Z-Value R Difference Score 26 1.550 1 0.223 -1.219 0.239 5.10 Discussion Prior research has found that cognitive style accounts for key differences between students with regard to social connectedness and visual perceptiveness. However, few investigations to our knowledge have studied how students' cognitive style may influence cognitive load, performance and content-based learning gains when using GLAR applications. Therefore,

the purpose of this study was to establish if there is a relationship between

students' cognitive style and cognitive outcomes when interacting with GLAR applications. Specifically, this study investigates how designing GLAR for individual differences in cognitive style may influence cognitive load, performance and content-based learning. The key findings are (1) cognitive load of FD students is significantly lower in the VonChigh condition relative to the other conditions when voice and coherence were manipulated, (2) FD students' cognitive load remained constant across the four experimental conditions when voice and coherence were manipulated, and, (3) both FID and FD students had content-based learning gains after engagement with Build-A-World. These findings add to the body of literature that cognitive style is an individual difference that can be linked to cognitive load and learning gains in GLAR. 5.10.1 Cognitive load (Research question 1) Exposing all students to each of the four experimental conditions allowed us to investigate which condition(s) help students develop their own personal strategies for interacting with Build- A-World. This study revealed that FD students experienced less cognitive load

in the VonChigh condition as compared to the other three voice × coherence conditions.

These findings could be interpreted as using tablet-based GLAR that embraces voice and coherence may support social connectedness and visual perceptiveness. Recall that social connectedness refers to the relationship students have with other students and voiceovers that provide positive feedback and vocal encouragement. Research conducted by Shaver and Goldenberg (2005) found that social connectedness could have important cognitive benefits and influence how students interact with information. Visual perceptiveness is students' ability to identify significant information from visual or textual content to associate with a more difficult learning task (Lyons-Lawrence, 1994; Liu & Reed, 1994). Further, studies show that FD students are generally not visually perceptive without assistance from the learning content or delivery mechanism (Kali, 2002). Since voice and coherence are known to support social connectedness and visual perceptiveness respectively, the results may suggest that GLAR interfaces that support voiceovers and visual cueing help FD students develop effective learning strategies which, in turn can reduce their cognitive load. These findings could also be due to the fact that voice guidance coupled with high coherence resulted in a structured and undifferentiated GLAR user interface. This interface in turn may have enabled FD students to more easily organize system-presented information, and ultimately lower the cognitive demand required to use the interface. On the other hand, FID students exhibited

no significant differences in cognitive load across **the** four **experimental** voice and coherence **conditions.**

These results support the notion that 186 the manner of information presentation (i.e., via voice and coherence) does not appear to affect FID students' visual perceptiveness. That is, FID students may be able to use many different GLAR interfaces to isolate important information without experiencing differing levels of cognitive load. Lastly it is known that, when faced with a large amount of information, FID students do not rely on social connectedness to develop strategies on how to select, organize and integrate important information into their mental models. 5.10.2 GLAR performance (Research question 2) In terms of performance, this study revealed that FD students had higher game scores as compared to FID students when using GLAR designed to provide social connectedness (i.e. when voice is on and coherence is high). This was a notable finding since it contradicts research findings that suggest FD students do not perform as well and score lower than FID students (Grieve & Davis, 1996), (Davis, 1991). One explanation for FD students' higher game scores could be that they worked harder than the FID students; a supposition supported by the fact FD students reported increased levels of cognitive load as compared to FID students. This try harder effect may be effective for now; however, in a longitudinal study we may see FD students experience fatigue and disengagement, which would potentially mitigate the relative performance gains. Although FID students had lower game scores as compared to FD students, FID students solved more problems with fewer mistakes than FD students which is aligned with other research findings. According to Ishmail and King (1985), FID students tend to achieve higher scores in mathematics on standardized tests because they are analytical and able to think abstractly to acquire algorithmic knowledge. Taken in sum, this study provides empirical evidence that designing GLAR applications that account for cognitive style offers promise to improve GLAR performance for FD students as measured by game score, but may not assist FD students in accurately answering questions related to learning content. 5.10.3 Content-based learning gains (Research question 3) Delivering learning content in a manner that is sensitive to individual differences and aligns with students' different cognitive styles can significantly impact student learning outcomes. We found that both FID and FD students had statistically significant content-based learning gains after engagement with the GLAR application. The positive increase in content-based learning gains for FD students may be attributed to the instructional design of GLAR using coherence and voice. That is, by leveraging voice coupled coherence may have reduced ambiguity and helped FID students relate to the learning content. Additionally, we found no meaningful differences between FD and

FID students' learning gains. A possible explanation for no significant findings could be contributed to the ceiling effect. Specifically, because FID

students scored an average 10 (of 10) on the pre-assessment, there was

little to no room for improvement in post-assessment score. According to Uttl (2005), ceiling effects occurs when "assessments are relatively easy so that a large proportion of participants obtain either maximum or near-maximum scores and the true extent of their abilities cannot be determined." Because we used standardized assessments, our ability to account for the ceiling effect in measuring differences between FID and FD students was limited. FID students have potentially stronger mathematical abilities than FD students (Lin, Hwang, & Kuo, 2009), thus to mitigate ceiling effect in future studies, the characteristics of participants should be carefully considered with regards to selecting or designing assessments. 5.10.4 Voice Principle In this study, the voice principle was manipulated to specifically help FD students by fostering social connectedness via positive feedback and encouragement, which in turn aimed to support deeper processing of instructional messages such as "The Aliens have just started their journey to Mars", and "You have 11 minutes to finish the landing strip. Keep working hard." FID students were expected to have comparable GLAR game scores for both voice-on and voice-off conditions. Although we observed improved FID student game scores when voice was on (as compare to voice off), we expected voice to be an unnecessary principle to respond to student's cognitive resources since the finding was not significant and FID do not typically rely on social connectedness to accomplish tasks or goals (e.g., answer questions in the marketplace). The body of literature on the voice principle is mixed, yet most studies report an increase in the degree of social connectedness perceived by the student (Moreno 2009; Mayer et al., 2003). Moreover, according to Durbridge, voiceovers such as those included in Build-A-World can improve cognition by adding clarity, meaning and motivation and by directly conveying a personal narrative that is more engaging than written text (Durbridge, 1984). We believe Build-A-World in turn, offers promise since our results suggest GLAR applications may reduce FD students' cognitive load and increase their performance. 5.10.5 Coherence Principle Since FD students are generally not visually perceptive and take a global approach to problem solving (Allinson & Hayes, 1996), we believe high coherence provided FD students with a minimalist interface where the visual information was (1) organized in a logical manner, and, (2) included only the necessary information needed to play the game. We did not observe that the coherence principle assisted FD students with visual perceptiveness and this could be due to the degree in which we manipulated conditions of coherence (i.e., differences in coherence conditions were not sufficient enough to determine differences in GLAR performance). However, we did observe that FD students had higher game scores than FID students in both low and high coherence interfaces; which was unexpected. When coherence was low, we expected FID students to have higher game scores than FD students because FID students are able to leverage more concurrent (and potentially distracting) information when developing their own cognitive strategies. According to Witkin et al. (1977), field independent students have the ability to create structure using their own cognitive schemes or strategies. Therefore, when there is no structure present in the material, FID students should have greater performance and reduced cognitive load (as compared to FD students since FID students can, in theory, employ their own strategies to distinguish relevant and irrelevant information. More research is needed to observe the inconsistencies we found in our study. 5.10.6 Implications To maximize learning outcomes in GLAR, it is useful to apply principles of CTML as well as employ techniques that account for cognitive differences among students. This study provides an example of how to design a tablet-based GLAR application that accounts for student cognitive style when delivering fifth grade area, perimeter and volume learning content. The findings suggest that accounting for cognitive style in GLAR interface design could help lower the cognitive load of both FD and FID students, which in turn, could improve their learning experiences. This research also offers evidence that utilizing the voice and coherence principles of CTML can lower cognitive load and increase content-based learning gains specifically for FD students. From the results of this study, it is difficult to determine whether or not varying combinations of voice and coherence can be creatively leveraged to improve learning experiences for FID students. 190 Most research examining cognitive style and CTML is conducted in laboratories under controlled conditions. Thus, a contribution of this work lies in the fact that we conducted this study in actual fifth grade classrooms, and thus the work provides insights into whether GLAR applications could actually be used in real-world environments. Literature on controlled laboratory research provides evidence supporting the use of CTML to meet the needs of both FD and FID students, while in a real-world environment using tablet-based GLAR, only FD students showed a reduction in cognitive load. The

results of this study reiterate the importance of accounting for **cognitive style differences**

amongst students when using tablet-based GLAR applications. However,

more research is needed to validate the use of

FID (as well as FD) traits to guide the design of future GLAR applications for use in classroom settings. 5.10.7 Assumptions and Limitations In this study, we assumed that all students had the same mathematical knowledge of area, perimeter and volume, which may not be accurate. In all likelihood, within and between groups, all students had varying levels of content knowledge because they had different mathematics teachers and came from different schools. Another assumption made was that fifth-grade participants have the ability to self-report their cognitive load experienced during the gamified AR activity. To support this assumption, it should be noted that researchers Gopher and Braune (1984) claim that elementary students were more than capable at providing a numerical value to assess their perceived stress, frustration and cognitive load. Lastly, we assumed that the GLAR interface differences in voice and coherence were sufficient enough to elicit differences in GLAR performance and cognitive load amongst students. There was limited pilot testing because of time constraints and limited availability to the target populations. Therefore, more research should include deeper pilot testing of GLAR applications to ensure that differences in students' reported cognitive load and GLAR performance are due to differences in interface design. A

limitation of this study is the small sample size **of** twenty-six **participants,**

which has clear ramifications for the generalizability of the study

to other content areas, grade levels and regions of the Country. Also, the sample of participants was not fully random due to recruitment of the specialized population. Therefore, the level of generalization is lower and we recommend increasing the sample size in future studies. The duration of exposure time to the GLAR application was another limitation of this study. Research states that FD students "require more time than FID students to complete tasks in computerized settings"

(Liu & Reed, 1994) and "more time in general to process information" **(Burton et al., 1995; Davis, 1991).**

Therefore, allowing FD students longer exposure times could possibly result in different cognitive load and student performance results. Lastly, since this research was not conducted in a controlled environment, there was some noise present in data collection methodologies such as environmental distractions, student stress, disengagement or off-task students, and interruptions. 6 Conclusion The increased development of educational technology has made it possible to provide students with hands-on, rich experiences aimed to ignite their passion for STEM and increase learning achievements. However, many students in K – 12 underserved communities do not have access to these technologies and thus are not equipped to achieve similar STEM educational levels of learning. This dissertation work aimed to examine the potential of commodity tablet-based GLAR applications as a supplemental learning tool in fifth grade classrooms at Title I schools, in hopes of identifying ways in which to minimize the achievement gap. There were three objectives working towards this aim; each grounded in the CTML theoretical framework: (1) understanding the role of prior knowledge on cognitive performance, (2) examining if adherence to CTML principles (developed for 2D multimedia learning) applies to gamified learning augmented reality, and, (3) investigating the impact of students' cognitive style on cognitive performance with GLAR. Objective one aimed to give direct insights into students' perspectives in regard to possible benefits and challenges of using GLAR, their perceived cognitive load and how prior knowledge may affect cognitive load and knowledge creation. Objective two examined how GLAR interfaces' degree of adherence to CTML principles effected students' cognitive load and performance. Objective three aimed to bolster the claim that utilizing cognitive style to inform the design of GLAR applications is an effective approach for accounting for students' cognitive differences. The results of this work suggest that GLAR applications grounded in CTML have potential as an effective supplemental tool that can be leveraged in fifth grade classrooms to enhance students' learning experiences. Specifically, this work further provides evidence that CTML may be an appropriate framework to ground and guide the development of GLAR applications that aim to reduce students' cognitive load. This work also shows the importance of considering individual 193 differences such prior knowledge and cognitive styles when designing GLAR applications. For example, we found that the same GLAR application used for students without prior knowledge students may not necessarily support the cognitive processes of students with prior knowledge. Additionally, our findings suggest that accounting for cognitive style in GLAR interface design could help lower the cognitive load of both

field-dependent and field-independent students, which **in** turn, could improve **their learning**

experiences and outcomes. 6.1 Research Contributions To the

best of our knowledge, this work is the first to

apply CTML's principles to the design of tablet-based GLAR applications. Therefore, this work contributed to literature by providing a set of empirical evidence on the unique benefits and challenges of utilizing augmented reality (AR) as a supplemental learning technique to reinforce mathematical concepts while responding to students' cognitive resources. Specifically, this work provides: ? Novel tablet-based GLAR applications for reinforcing mathematical concepts, Celestial Blast and Build-A-World ? A new novel base of knowledge for researchers, designers and practitioners to consider by providing a starting point for other researchers interested in designing tablet-based GLAR applications for K – 12 STEM and other fields. ? Empirical evidence on the effects of adherence to CTML principles when designing GLAR applications to maximize students' cognitive outcomes ? Empirical data

on the relationship between students' perceived benefits **and the impact** of GLAR **on** students' **cognitive load.** ? An understanding of **the**

pedagogical value of tablet-based GLAR applications ? A mixed-methods study on GLAR that utilized quantitative and qualitative research to gather students' perspectives. The qualitative findings in this study were able to add new layers of support, rationale and explanation to quantitative results. ? Students' perspectives as a way to improve the development of future K – 12 GLAR applications. ? Evidence that suggests designing GLAR to consider individual differences such as prior knowledge and cognitive styles can improve students' learning and cognitive outcomes. ? A usability evaluation for understanding the impact and consequences of combining multiple design principles of CTML to inform GLAR applications. 6.2 Recommendations for design considerations This research offers recommendations as well as design considerations to assist with the development of future K – 12 GLAR applications. These recommendations were derived from lessons learned through conducting this dissertation work. 1. Design applications to highlight the features and affordances of GLAR such as engaging students in multi-modal sensory and spatial tasks. 2. AR excels at augmented the real-world, so leverage the "real-world" classroom as part of the GLAR application design. 3. Create interactive experiences that encourage students to get up, and move, and to view virtual content from many perspectives (another advantage AR affords). 4. Develop personalized versions of GLAR applications to support individual differences. a. Provide corrective feedback so students can adjust their performance to adopt more productive learning strategies; b. Provide scaffolding to enhance individualized learning outcomes; 195 c. Customize the pace and delivery of learning content so GLAR applications meet the needs of all students; d. Provide level selection so students can determine where they want to start interacting with GLAR (thus supporting varying levels of students' prior knowledge), and; e. Provide a hint or help button so students can receive assistance if they are having difficulty. 5. Incorporate built in assessments to allow students and potentially teachers to see what students are learning from, and during the engagement with GLAR. 6. Conduct usability evaluations with student and teachers to gather specific feedback on GLAR application throughout the development process. Incorporate feedback into future iterations of the GLAR application to improve the experiences of your users. 7. Be cautions when selecting themes or stories that guide the design of GLAR applications. Unrealistic themes may cause students to become disengaged in the learning activity if they cannot relate to the learning content. 8. Design multiplayer GLAR applications to foster collaborative learning. 6.3 Future Research Payne-Tsoupros (2010) cautioned the educational community in that attempting to close the achievement gap may actually result in "high-achieving students regressing toward the mean instead of the low-achieving students improving." Additional research is needed to investigate how both high- and low- achieving student learning is effected from engaging with GLAR. This can be observed by collecting longitudinal data which provides researchers with a richer and more complete understanding on GLAR's impact on achievement, and what improvements could be made to GLAR ensure all students are improving. Another opportunity

for future research **is to** investigate **what** other learning **content** areas **can be effectively** reinforced **using** GLAR **and what** learning **content**

areas are difficulty to deliver. For example, our study provides evidence that GLAR can reinforce mathematical spatial learning content on angles, area and perimeter, but for example, GLAR may not be a fit for understanding 18th century English literature.

It is important for future research to acknowledge the limitations of GLAR **to**

increase student learning outcomes whilst also supporting student cognitive resources and to study the types of learning activities GLAR applications are well-suitable for. Finally, learning applications are being designed without considering the perspectives of educational stakeholders on how technology can be effective leveraged in the classroom (Cuban, 2003). Investigating teachers' perceptions would help identify what difficulties they face in the classroom and how GLAR could be potentially integrated into the classroom to address those difficulties. Further, future research can examine to what extent teachers require training when integrating GLAR in the classroom. References Abramovich, S., Schunn, C., & Higashi, R. M. (2013). Are badges useful in education?: It depends upon the type of badge and expertise of learner. Educational Technology Research and Development, 61(2), 217-232. Act, N. C. L. B. (2001). United States Department of Education. Public Law, 107-110. Ahn, J. 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User Satisfaction Survey for High Adherence Interface Appendix I. User Satisfaction Survey for Medium Adherence Interface Appendix J. User Satisfaction Survey for Low Adherence Interface Appendix K. User Satisfaction Survey for VonClow Interface Appendix O. User Satisfaction Survey Results Chapter 4 All participants completed a user satisfaction survey on their evaluation and opinions about the three GLAR interfaces on a Likert Scale of 1 to 5, with 1 being no and 5 indicating yes. Tables 42, 43 and 44 displays the descriptive statistics for each question. Table 42. Means and Standard Deviations of User Satisfaction Survey Results for

High Adherence Interface Questions Mean SD 1. Was it too much information presented? 1.94 1.03 2. Was the graphics distracting or annoying? 2.61 1.04 3. Did the graphics help you understand the angles? 4.49 1.23 4. Was the sound distracting or annoying? 2.89 0.96 5. Did the sound help you protect the town? 4.49 0.89 6. Was it too much sound and graphics? 3.00 1.23 7. Did the colors (red, yellow and blue) on the asteroid help you protect the town? 4.86 1.38 8. Did the voice help you to know where the asteroid was coming from? 3.86 1.01 9. Did the town changing colors help you protect the town? 2.97 1.20 10. Did the health bar help you protect the town? 3.43 1.04 11. Was the meaning of the graphics easy to understand? 3.31 1.09 12. Did hearing the sound and seeing the graphics at the same time help play the game? 3.05 1.00 13. Did seeing the angle classification and number at the bottom help you protect the town? 4.37 1.06 Table 43.Means and Standard Deviations of User Satisfaction Survey Results for Medium Adherence Interface Questions Mean SD 1. Was it too much information presented? 3.88 1.16 2. Was the graphics distracting or annoying? 3.00 0.97 3. Did the graphics help you understand the angles? 3.57 1.12 4. Was the sound distracting or annoying? 4.49 0.97 5. Did the sound help you protect the town? 3.29 1.20 6. Was it too much sound and graphics? 3.43 1.22 7. Did you play attention to the score while playing? 4.66 1.19 8. Did the voice help you to know where the asteroid was coming from? 3.37 0.99 9. Was it distracting or annoying having multiple towns? 4.40 1.14 10. Was the meaning of the graphics easy to understand? 1.94 1.03 11. Was hearing the sound and seeing the graphics at different times stressful? 3.34 1.06 12. Do you want the angle classification and number to be displayed closer together? 2.97 1.12 Table 44. Means and Standard Deviations of User Satisfaction Survey Results for Low Adherence Interface Questions Mean SD 1. Was it too much information presented? 1.09 1.01 2. Was the graphics distracting or annoying? 2.07 1.17 3. Did the graphics help you understand the angles? 3.06 0.87 4. Was the dancing man a distracting or annoying? 2.37 1.10 5. Do you want the game to have sound? 4.23 1.06 6. Was it too many graphics? 3.17 1.07 7. Did you play attention to the score while playing? 4.31 1.12 8. Did you play attention to the UFO? 4.43 0.87 9. Was it distracting or annoying having multiple towns? 3.98 1.00 10. Was the meaning of the graphics easy to understand? 2.89 0.96 11. Was it difficult to play the game? 4.95 0.88 12. Do you want the information to be displayed closer together? 4.63 1.38 Appendix P. User Satisfaction Survey Results Chapter 5 All participants completed a user satisfaction survey on their evaluation and opinions about the GLAR interfaces when voice and coherence is manipulated on a Likert Scale of 1 to 5, with 1 being no and 5 indicating yes. Tables 45, 46, 47 and 48 displays the descriptive statistics for each question. Table 45. Means and Standard Deviations of User Satisfaction Survey Results for VoffClow Interface Questions Mean SD 1. Do you want the game to have sound? 3.68 1.89 2. Not having sound allowed me to focus on the mission. 2.48 1.30 3. If the app had a talking voice, you could play the game better. 4.05 1.21 4. Do you wish the game had a voice encouraging you while playing the game? 3.97 1.56 5. If the app had a talking voice, it would have been distracting? 2.67 1.08 6. Was reading the words while playing the game distracting? 3.94 1.49 7. Did the words help you complete the mission? 3.73 1.07 8. Did you notice the UFOs? 4.08 0.98 9. Was the dancing man distracting? 1.42 1.12 10. Was there too much graphics? 2.43 1.39 11. Did you pay attention to the score when playing the game? 4.57 1.04 12. Did you pay attention to the number of blocks displayed at bottom of screen? 1.65 1.44 13. Was seeing words like “Nice” encouraging? 3.87 1.01 14.

Do you think you can accomplish the mission without the positive feedback? 2.13 0.97 15. Was reading the words while playing the game distracting? 3.82 1.49 16. Did you play attention to the UFOs? 2.37 1.12 17. Did seeing the blocks on your desk help you understand perimeter? 3.05 1.38 18. Was the game fun? 4.65 1.01 19. Was playing the game hard? 4.88 1.09 20. Was reading the words on the screen easy? 3.82 1.42 21. Was it easy to learn to play the game? 1.05 0.86 22. Did placing the blocks help you understand perimeter? 4.45 1.11 23. Did answering the questions help you to learn more about area, perimeter and volume? 3.50 1.24 24. Was placing the blocks easy? 3.57 1.56 25. Was answering questions in the market place easy? 3.43 1.02 Table 46. Means and Standard Deviations of User Satisfaction Survey Results for VoffChigh Interface Questions Mean SD 1. Do you want the game to have sound 4.60 1.39 2. Not having sound allowed me to focus on the mission. 1.86 1.49 3. If the app had a talking voice, you could play the game better. 3.86 1.49 4. Do you wish the game had a voice encouraging you while playing the game? 4.45 1.07 5. If the app had a talking voice, it would have been distracting? 3.00 1.27 6. If the app had animations, it would have been distracting. 4.86 1.33 7. Was there too much graphics? 4.66 1.19 8. If the app had positive feedback, you could play the game better. 2.63 1.16 9. Do you wish the game showed you the score while you were playing? 4.03 1.28 10. Not having a talking voice allowed me to focus on the mission. 2.63 1.08 11. If the app had positive feedback, it would have been distracting 3.30 1.86 12. Did seeing the blocks on your desk help you understand perimeter? 4.54 1.61 13. Was the game fun? 2.89 1.07 14. Was playing the game hard? 3.73 1.22 15. Was reading the words on the screen easy? 3.67 1.76 16. Was it easy to learn to play the game? 1.69 1.11 17. Did placing the blocks help you understand perimeter? 3.36 1.09 18. Did answering the questions help you to learn more about area, perimeter and volume? 3.66 1.31 19. Was placing the blocks easy? 3.67 1.29 20. Was answering questions in the market place easy? 3.31 0.94 Table 47. Means and Standard Deviations of User Satisfaction Survey Results for VonClow Interface Questions Mean SD 1. Did you notice the talking voice? 3.69 1.13 2. Did the voice help you complete the mission? 2.40 1.14 3. Did the talking voice help you get a higher score? 3.94 1.07 4. Did hearing “good job” encourage you? 3.57 1.20 5. Were the voice alerts distracting? 2.66 1.19 6. Did you pay attention to the talking voice? 3.69 1.17 7. Was reading the words while playing the game distracting? 4.57 0.98 8. Did the words help you complete the mission? 2.49 1.01 9. Did you notice the incoming UFOs? 3.46 1.09 10. Was there too much sound and graphics? 2.54 1.44 11. Did you pay attention to the score when playing the game? 2.74 1.40 12. Did you pay attention to the number of blocks placed displayed at bottom of screen? 2.51 1.27 13. Was seeing words like “Nice” encouraging? 3.51 1.38 14. Do you think you can accomplish the mission without the positive feedback? 2.09 1.01 15. Was reading the words while playing the game distracting? 3.17 1.07 16. Did you play attention to the dancing man? 3.97 1.10 17. Did seeing the blocks on your desk help you understand perimeter? 3.37 1.00 18. Was the game fun? 3.37 0.97 19. Was playing the game hard? 4.49 0.89 20. Was reading the words on the screen easy? 3.37 0.97 21. Was it easy to learn to play the game? 3.34 0.94 22. Did placing the blocks help you understand perimeter? 4.27 1.09 23. Did answering the questions in the market place help you to learn more about area, perimeter and volume? 2.87 1.13 24. Was placing the blocks easy? 4.05 0.89 25. Was answering questions in the market place easy? 4.21 0.91 Table 48. Means and Standard Deviations of User Satisfaction Survey Results for VonChigh Interface Questions Mean SD 1. Did you notice the talking voice? 4.52 0.97 2. Did the voice help you complete the mission? 4.24 0.89 3. Did the talking voice help you get a higher score? 3.63 1.00 4. Did hearing “good job” encourage you? 4.71 1.13 5. Were the voice alerts distracting? 1.89 0.96 6. Did you pay attention to the talking voice? 4.00 1.03 7. If the app had animations, it would have been distracting. 2.06 0.87 8. Was there too much sound and graphics? 1.29 1.20 9. If the app had positive feedback, you could play the game better. 3.34 1.06 10. Do you wish the game showed you the score while you were playing? 3.83 0.90 11. If the app had positive feedback, it would have been distracting. 3.31 1.08 12. Did seeing the blocks on your desk help you understand perimeter? 3.57 1.12 13. Was the game fun? 4.43 1.22 14. Was playing the game hard? 3.97 1.19 15. Was reading the words on the screen easy? 2.46 1.54 16. Was it easy to learn to play the game? 2.69 1.13 17. Did placing the blocks help you understand perimeter? 3.51 1.38 18. Did answering the questions help you to learn more about area, perimeter and volume? 4.69 1.13 19. Was placing the blocks easy? 3.66 1.19 20. Was answering questions in the market place easy? 3.37 0.97 Appendix F. Pre- Assessment for Chapter 5 Appendix G. Post- Assessment for Chapter 5 Appendix L. User Satisfaction Survey for VoffClow Interface Appendix M.User Satisfaction Survey for VonChigh Interface Appendix N. User Satisfaction Survey for VoffChigh Interface 1 5 6 7 8 9 10 11 13 16 17 18 20 23 24 25 29 31 32 34 36 38 39 40 42 43 44 45 46 47 48 49 50 51 53 54 55 56 57 58 59 60 64 65 66 68 71 73 74 75 76 77 78 79 80 81 83 84 85 86 87 88 89 90 91 92 93 95 98 99 100 101 102 103 104 105 106 108 109 110 111 112 114 115 116 117 118 119 120 121 122 123 125 126 127 128 129 130 131 132 134 135 137 140 141 142 143 144 146 147 148 149 152 153 155 157 158 159 160 161 162 164 165 166 168 169 170 171 172 174 175 176 177 178 180 181 182 183 184 185 187 188 189 191 192 194 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249