THE EFFECT OF INTERNET-BASED MULTIMEDIA READING ENVIRONMENTS ON UNDERGRADUATE STUDENTS' READING COMPREHENSION

by

KRISTI A. LEONARD

(Under the Direction of Robert Maribe Branch)

ABSTRACT

This study investigated the application of the cognitive theory of multimedia learning's multimedia principle on reading comprehension, specifically in Internet-based reading environments with undergraduate students. Participants that completed the study were assigned to one of two treatment groups: text only and text and graphics. Participants completed a prior knowledge test, spatial ability test, reading comprehension test, and a cognitive load questionnaire. An ANCOVA was used to analyze the reading comprehension differences between the treatment groups, text only and text and graphics. The results of the study indicated that the inclusion or exclusion of graphics had no impact on reading comprehension. Additionally, correlational analysis was used to investigate the impact that the learner characteristics prior knowledge, spatial ability, and cognitive load had on reading comprehension. The results of the study indicated that overall, higher prior knowledge and higher spatial ability were beneficial to reading comprehension and higher cognitive load was detrimental to reading comprehension.

INDEX WORDS: Cognitive theory of multimedia learning, Reading comprehension, Multimedia, Cognitive load theory, Spatial ability, Prior knowledge

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DEDICATION

To the love of my life,

and to my bug,

I love you both.

Thank you for sticking with me, constantly

supporting me, and loving me.

I share this achievement with you.

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CHAPTER 1

INTRODUCTION

Many readers engage in Internet-based reading on a daily basis. Internet-based newspaper readership alone has almost doubled, growing from 41,445,617 readers in January 2004 to 73,310,561 readers in July 2009 (Anderson, 2009). Internet users also reported reading email (90%), searching for information (89%), or reading the news (73%) while online (Pew Internet & American Life Project Surveys, 2008). Web sites combine text, images, and hyperlinks that may support or hinder readers' reading comprehension. In fact, "The average web page contains 8.87 images per page" (Pons, 2006, p. 104), while the "average number of hyperlinks per web page is 10.70" (Pons, 2006, p. 104). The reading environment is rapidly changing with the advent of the Internet and other digital technologies, evolving from predominantly paper-based to predominantly Internet-based presentations. Thus, Internet-based readers are required to recognize, interpret and comprehend content within a multimedia environment that was inherently different from common paper-based reading environments. Readers who are reading on the Internet are engaging in multimedia reading.

The physical process of reading is changing. Karchmer (2001) and Sutherland-Smith, (2002) proposed that the change in the process of reading was due to the introduction of the Internet. Although readers have been engaging in Internet-based reading more often, it has not clearly understood how Internet-based multimedia reading affects the reader's comprehension. Furthermore, the ability to read and comprehend textual information has been integral to all schooling and indeed to living a productive and fulfilling life in developed areas of the world

(Brandt, 2001). As more reading opportunities become available on the Internet and our society embraces the Internet-based multimedia reading environment, a more in-depth understanding of how multimedia environments affect the reader's comprehension is necessary.

Multimedia Reading Defined

Internet readers develop understanding from digitally presented text, but more often than not, Internet readers are also interpreting digitally presented multimedia. Internet readers are engaging in multimedia reading. Just and Carpenter (1987) stated that, "reading is a complex cognitive skill, consisting of a collection of psychological processes that together produce an understanding of text" (p. 3). Reading requires the reader to recognize symbols and decipher words from the combination of these symbols, often called word recognition. Recognizing words is only the first step. In addition, a reader needs to understand and make meaning from these words and incorporate the information into existing schema in long-term memory, a process termed comprehension.

Multimedia for this study is defined as an artifact that uses multiple modes to express or communicate. Multimedia includes Internet-based multimedia reading environments that present text, static images, and dynamic images synchronously. Internet-based multimedia reading environments use multiple modes and multiple medias to convey information. Therefore, multimedia reading is the cognitive process of making meaning from multiple modes of expression or communication that include visual text and at least one other mode, such as static or dynamic graphics.

Rationale

Opportunities for adults to complete reading tasks online are increasing daily. Twenty-five percent of university students brought laptops to campus in 2001 (Crews, Brown, Bray &

Pringle, 2007); however, in 2008, the number of students who brought laptops to campus increased to 80.5% (Salaway & Caruso, 2008). Further, 93.4% of students who participated in the EDUCAUSE Center for Applied Research (ECAR) survey used their library's web site to search for information. Students are clearly engaging in online reading tasks.

The influx of portable, wireless technology has forced new methods of communication and data distribution to be used by instructors and students. Camp and DeBlois (2007), in conjunction with the nonprofit association, EDUCAUSE, whose mission is to advance higher education by promoting the intelligent use of information technology, reported that along with the increased use of wireless computing devices, more than 90% of campuses supported at least one content management system or learning management system such as Blackboard, Sakai, or Moodle for instruction (Camp & DeBlois, 2007).

Blackboard is an Internet-based content management system that enables students and faculty to teach, participate, and collaborate online. Blackboard offers faculty and students Internet access to course materials, discussion boards, virtual chat, online quizzes, and an academic resource center. Sakai is a content management system designed to help instructors, researchers and students collaborate online. Sakai offers collaboration tools such as: email, wikis, blogs, calendars, chat rooms, discussion forums, lessons, and assignments. Moodle is a software package for producing Internet-based courses and web sites. Moodle features an assignment, chat, survey, forum, and wiki module that allowed participants to upload assignments in any file format, synchronous text interaction, voting, discussion with text and multimedia, contribute content, embed descriptive text and graphics, and create collaborative web pages that anyone can add to or edit.

Course content distributed to students through a content management system, learning management system, or digital library make almost all reading tasks available electronically. Internet-based resources present information using static and dynamic images, visual text, and oftentimes, audible text (Pons, 2006). Additionally, Internet-based content is commonly distributed over several pages, non-linear, and joined together with hyperlinks. The process of reading from Internet-based resources employs different physical and cognitive challenges than reading from print-based resources. Swaffar, Arens, and Byrnes (1991) stated that "fluent readers synthesize textual subsystems (e.g., content, context, intent, language) into a larger metasystem of meaning" (p. 21) and that "in short, readers comprehend a text when they construct a mental representation for incoming pieces of verbal information" (p. 22). The RAND Reading Study Group (2002) reported, "electronic texts that incorporate hyperlinks and hypermedia introduce some complications in defining comprehension because they require skills and abilities beyond those required for the comprehension of conventional, linear print" (p. 14). Mental representations may be more difficult to piece together from Internet resources that are commonly distributed over several pages, non-linear, and joined together with hyperlinks. Reading comprehension is complex, but the Internet-based components that are common to online reading environments may make the process of reading comprehension even more cognitively complex.

The use of multimedia in instructional print settings has a long history dating to as early as the 14th century where representative graphics were used to support text (Figure 1). However, research on multimedia's effectiveness in instructional settings has had a much shorter existence. There have been a limited number of studies investigating the effectiveness of instructional media, and most of them have been in the form of media comparison studies, resulting in nonspecific conclusions explaining that the context, subject, and learner characteristics greatly affect the outcome (Reiser, 2007). Rieber (1994) explained, "There are times when pictures can aid learning, times when pictures do not aid learning but do no harm, and times when pictures do not aid learning and are distracting" (p. 15). In other words, the effectiveness of instructional media depends on a number of confounding factors.

Designers create Internet-based multimedia reading environments based on design trends, technological capabilities, client expectations, and aesthetics. There are several resources for designers that guide the technical aspects of web page creation including the World Wide Web Consortium and their *Web Content Accessibility Guidelines*. However, there are few overarching guidelines to aid in the design of multimedia environments that support learning for all learners (Clark, Lyons, & Hoover, 2004). Furthermore, design guidelines specifically for the support of reading comprehension are virtually nonexistent.

There has been a tendency for Internet design studies to focus on learning transfer, which is very important. Harp and Mayer (1997, 1998), Kalyuga, Chandler, and Sweller (1999, 2000), and Moreno and Mayer (1999, 2000, 2002) focused multimedia learning research on the transfer of knowledge and ignored reading comprehension as an instructional outcome. However, it is imperative that designers have access to structured guidance for making decisions about the use of multimedia, not only for knowledge transfer, but for reading comprehension as well (Kress & Van Leeuwen, 2001; Rieber, 1994). Structured guidance will make it possible for designers to easily, effectively and economically create multimedia learning environments that support knowledge transfer and reading comprehension.

Figure 1. Illustration of medieval surgical instruments that was included in *Chirurgia magna* (Great Surgery), Guy de Chauliac, 1363.

Multimedia reading environments should be designed with the overall instructional goal in mind, comprehension. Readers may suffer from effects that are detrimental to comprehension when completing multimedia reading tasks including split-attention, lack of coherence, and cognitive overload (Reinking, 2005); however, multimedia learning environments that are designed with the learner and the instructional goal in mind may eliminate these detrimental effects and support learning, comprehension, retention, and retrieval (Clark & Paivio, 1991; Mayer, 2009; Paivio, 1990, 1991; Schnotz, 2005; Tversky, Morrison, & Betrancourt, 2002). The design of multimedia learning environments may impact the multimedia reader's comprehension.

Mayer (1997) proposed the cognitive theory of multimedia learning (CTML) to address the detrimental and supportive effects that multimedia has on the learner (Figure 2). The cognitive theory of multimedia learning was grounded in the following cognitive theories:

1. Paivio's (1986; Clark & Paivio, 1991) dual coding theory posited that humans have two processing channels, verbal and imaginal. Visual and verbal information are processed through distinct sensory channels, and as a result, the human mind creates different representations of information processed in each channel. Hartland, Biddle, and Fallacaro (2008), explained that, "dual coding theory argues that inputted information may be easier to absorb (retain) and use (retrieve) when dual coding of that information occurs" (p. 197).
2. Baddeley's (1992) model of working memory posited working memory and long-term memory were the two major components that formed human cognitive architecture. Working memory holds incoming information and processes it to make meaning; however, working memory has a very limited capacity of approximately 5-7 pieces of information.

3. Sweller's (Chandler & Sweller, 1991; Sweller, Chandler, Tierney & Cooper, 1990) cognitive load theory, posited that due to the limitations of the capacity of working memory, demands on the information processing system may exceed the learner's capacity causing cognitive overload.
4. Mayer's (1996) select, organize, and integrate (SOI) model of meaningful learning explained that "there are three cognitive processes involved in meaningful learning" (p. 357). The three processes included selection, organization, and integration of presented information.

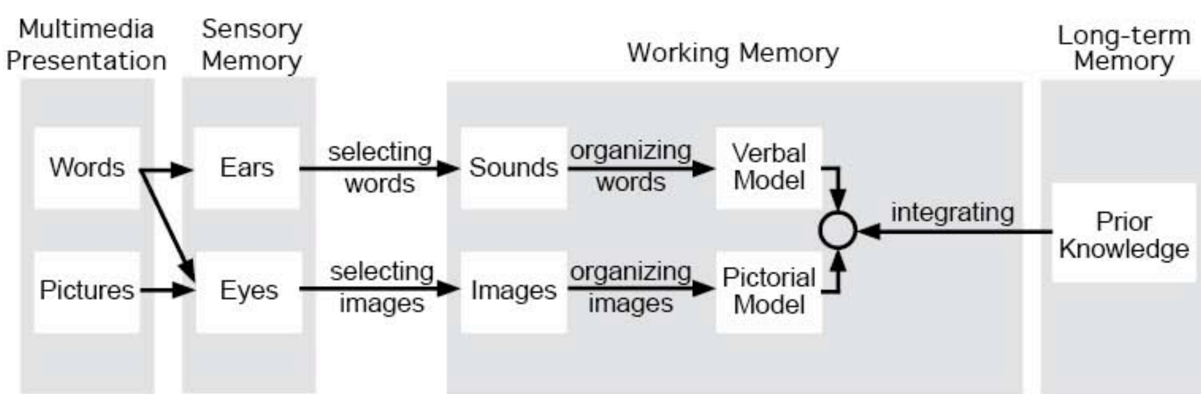


Figure 2. Mayer's (2008) framework for the cognitive theory of multimedia learning.

According to Mayer's CTML, the learner processes information cognitively through selection, organization, and integration. The first cognitive process, selection, describes how a learner handles incoming "verbal information to yield a text base" (Mayer & Moreno, 1998, p. 2) and its application "to incoming visual information to yield an image base" (Mayer & Moreno, 1998, p. 2). Organization, the second cognitive process, describes the process the learner applies to “the word base to create a verbally-based model of the to-be explained system” (Mayer & Moreno, 1998, p. 2) and its application “to the image base to create a visually-based model of the to be-explained system” (Mayer & Moreno, 1998, p. 2). Integration is the third cognitive process, and describes how the “learner builds connections between corresponding events (or states or parts) in the verbally-based model and the visually-based model” (Mayer & Moreno, 1998, p. 2). Therefore, multimedia reading environments enabled the reader to build verbal and visual bases and increased the number of connections between corresponding events; however, processing both visual and verbal information simultaneously may overwhelm the learner’s limited working memory capacity.

Mayer (2009) supplemented the three cognitive processes that explained multimedia learning by proposing the following ten principles to guide the design of multimedia learning environments:

1. Principles for reducing extraneous processing in multimedia learning included:
    a. *Coherence principle* explained that people learn better when all extraneous verbal and imaginal information is removed;
    b. *Signaling principle* explained that people learn better when indicators are used to highlight pertinent material and the organizational structure;
    c. *Redundancy principle* explained that people learn better graphics and audible text rather than graphics, audible, and visual text;
    d. *Spatial contiguity principle* explained that it was better for the learner to present words and images close together rather than spaced far apart or separated;

   e. *Temporal contiguity principle* explained that people learn better when corresponding graphics and text were present on a single page rather than on multiple successive pages;

2. Principles for managing essential processing in multimedia learning included:
   a. *Segmenting principle* explained that people learn better when multimedia instruction was segmented into user-paced units rather than one continuous unit;
   b. *Pre-training principle* explained that people learn better from multimedia instruction when they were introduced to the key names, terms, and main concepts prior to viewing the instruction;
   c. *Modality principle* explained that people learn better from graphics and audible text than from graphics and printed text;
3. Principles for fostering generative processing in multimedia learning included:
   a. *Multimedia principle* explained that people learn better from graphics and text than from text alone;
   b. *Personalization, voice, and image principle* explained that people learn better from multimedia presentations when text was personal and conversational rather than formal.

According to Mayer's (2009) cognitive theory of multimedia learning, many Internet-based resources hinder learning by causing split-attention, lack of coherence, and cognitive overload. Mayer contends that the application of the cognitive theory of multimedia learning principles to the design of multimedia learning environments may have a positive affect on the learning outcome; however, not all cognitive theory of multimedia learning principles apply to all learning environments simultaneously. The application of cognitive theory of multimedia learning principles depends on the instructional context, mode of delivery, and the learning objectives.

The application of the cognitive theory of multimedia learning principles to the multimedia reading environment depends on the following factors: 1) the presence of visual text, 2) the presence of graphics, and 3) the necessity to read the visual text; audible text cannot be present because it eliminates the necessity to read the visual text. In addition, some of the principles are inappropriate for a reading comprehension testing environment. For example, the pre-training principle explains that people learn better from multimedia instruction when they are introduced to the key names, terms, and main concepts prior to viewing the instruction. Introducing the key names, terms, and main concepts prior to reading the essay could affect the reading comprehension test scores. Figure 3 highlights the cognitive theory of multimedia learning principles that may apply to the design of multimedia reading environments including the coherence principle, signaling principle, spatial contiguity principle, temporal contiguity principle, modality principle, and the multimedia principle.

Just as Mayer (2009) contends that the use of these cognitive theory of multimedia learning principles may have a positive effect on learning outcomes, it may also be possible that multimedia reading environments designed based on the cognitive theory of multimedia learning principles may positively affect reading comprehension outcomes. However, the effect that the cognitive theory of multimedia learning principles may have on multimedia reading comprehension is unknown due to the dearth of research in this area.

CTML Principle	Graphics	Visual Text	Audible Text	Requires Reading	Not Appropriate for Comprehension Testing
Coherence principle	MI	MI	MI	MI	
Signaling principle	MI	MI	MI	MI	
Redundancy principle	MI		MI		
Spatial contiguity principle	I	I		I	
Temporal contiguity principle	I	I		I	
Segmenting principle	I	MI	I		
Pre-training principle					X
Modality principle	I	NI	I		
Multimedia principle	I	MI	MI	MI	
Personalization, voice, and image principle					X

Included (I); May be included (MI); Not Included (NI)

Figure 3. Principles of the cognitive theory of multimedia learning that may apply to the design of multimedia reading environments.

Text comprehension in multimedia reading environments is the issue. Reading and comprehension are necessary tools for attaining success in everyday contemporary life (Brandt, 2001). Designing multimedia reading environments that support reading comprehension is of the utmost importance, especially with the increased amount of reading people are engaging in on the Internet. Research that addresses the design of multimedia reading environments for optimum reading comprehension has become necessary.

Importance

Beyond reading and comprehension being necessary tools for attaining success in everyday contemporary life, comprehension is a general education goal for most learning contexts. Additionally, comprehension is the ultimate goal of reading instruction, but unlike decoding, it entails ill-defined, open-ended, and complex cognitive processes (Paris, 2005). Although it is currently unknown how multimedia reading affects comprehension, readers are continually asked to engage in multimedia reading and to comprehend more information from Internet-based multimedia reading environments everyday. Internet-based multimedia reading environments include content management systems, library websites and the World Wide Web in general.

The numerous web pages that present audible and visual text and static and dynamic graphics, in addition to hundreds of links and advertisements could be overwhelming to the reader, potentially causing cognitive overload deterring an individual’s ability to retain and retrieve the presented information. The effect that multimedia reading has on reading comprehension is not understood. It is difficult to compare reading comprehension from printed sources to electronic sources because both processes of reading employed different physical and cognitive challenges.

Multimedia environments designed to support the learner and encourage comprehension and knowledge transfer may be beneficial to all Internet readers, but how effective multimedia learning environments should be designed remains unknown. The cognitive theory of multimedia learning principles may provide insight to guide the design of multimedia environments intended for reading; however, the research grounding the cognitive theory of multimedia learning focuses on knowledge transfer rather than reading comprehension. Mayer (2009) developed 10 cognitive theory of multimedia learning design principles to guide the development of multimedia learning environments that support knowledge transfer. Most of the supporting research that instigated the establishment of the cognitive theory of multimedia learning principles demonstrated a positive effect on learning outcomes when the principles were followed. However, there is a need to determine if the cognitive theory of multimedia learning design principles have the same positive effect on a reader's comprehension.

Research Questions

Many readers engage in multimedia reading daily through their use of the Internet. The majority of the websites readers access combined text, images, and hyperlinks and are categorized as multimedia environments. Multimedia learning environments may affect the reader both positively and negatively. Multimedia environments designed to support the learner and encourage comprehension and knowledge transfer may be beneficial to all Internet readers. However, Mayer (Mayer, 2005; Mayer, Heiser, & Lonn, 2001) found that learners commonly experienced cognitive overload or split-attention effects during simultaneous presentations of visual images and visual text. Do adult readers also experience cognitive overload when *reading* in multimedia environments such as the Internet? This research study will try to answer the question, “Do multimedia reading environments designed based on the cognitive theory of multimedia learning affect readers’ reading comprehension?”

The cognitive theory of multimedia learning research that was conducted to develop the design principles found that learning environments that are designed based on the CTML principles resulted in more positive knowledge transfer learning outcomes than multimedia learning environments that ignored these principles. Are these principles transferable to the design of the multimedia reading environment? Answering this single question has the potential to drive a research agenda for several years. To address the overwhelming breadth of the research question, the study was limited to a more specific and narrow focus that enabled the research to more deeply investigate the principles of cognitive theory of multimedia learning. The main research question is: Do multimedia reading environments designed based on the cognitive theory of multimedia learning’s multimedia principle affect readers’ reading comprehension? Additional sub-questions have been developed to frame this research study around the cognitive theory of multimedia learning’s multimedia principle and the design of multimedia reading comprehension environments:

1. Do reading comprehension scores differ between readers who read text-only essays and readers who read graphics and text essays?
2. Do reading comprehension scores differ between questions that are directly related to included graphics and questions that are indirectly related to included graphics?
3. Do multimedia reading environments affect readers’ self-reported cognitive load?
4. Does a reader’s self-reported cognitive load change based on spatial ability?
5. Does a reader’s reading comprehension test scores change based on the reader’s prior knowledge?

6. Does a reader’s cognitive load change based on the reader’s prior knowledge?
7. Does a reader’s reading comprehension scores change based on the reader’s spatial ability?
8. Does a reader’s reading comprehension test scores change based on the reader’s cognitive load?

CHAPTER 2

REVIEW OF RELATED LITERATURE

Internet-based multimedia reading is a common contemporary practice that may affect reading comprehension. Furthermore, innate learner characteristics may also impact how well we learn and comprehend from multimedia reading environments. Given the nearly ubiquitous demands that contemporary and emerging technologies place on readers today, questions about multimedia reading need to be addressed through more and better educational research. However, before research studies can be appropriately designed and implemented, it is essential to review the existing research literature related to these questions. Accordingly, this review of literature is focused on the following topics: cognitive models of reading comprehension, cognitive theories that may support multimedia reading comprehension, learner characteristics that may affect multimedia reading, and the effect of multimedia reading on comprehension.

To summarize, a plethora of research has been conducted around the cognitive theory of multimedia learning and cognitive load theory. However, very little of this research focuses on the measure of reading comprehension; the focus had been on knowledge retention, knowledge transfer, task completion, multimedia learning, and the principles of the cognitive theory of multimedia learning. To the detriment of reading advocates, much of the research supports the idea that learners learned best from multimedia environments when text is audible and images are visual, eliminating visual text and the necessity to read altogether. The overall purpose of this literature review is to investigate what is known about multimedia learning and its application to multimedia reading environments that, in turn, will support reading comprehension.

Cognitive Models of Reading Comprehension

Reading comprehension is a complicated cognitive process that has been investigated for decades. Cognitive psychologists such as Gough (1972), Just and Carpenter (1980), Goodman (1965, 1967, 1994), and Kintsch (1988, 1998) developed reading comprehension models based on their research and understanding of the process of reading and comprehension. Three categories of reading comprehension processing models include: (1) bottom-up or data-driven, (2) top-down or conceptually driven, and (3) interactive.

Bottom-up processing models of reading focus on textual decoding and processing of letters, words, phrases, sentences, and paragraphs, in the process of constructing meaning while reading. Gough (1972) introduced his data-driven model, based on eye-tracking research. Employing eye-tracking observations he identified fixations, when a reader focused on a certain point in the text, and saccades, when a reader moved from one point in the text to another. Gough's data driven model is one of the most well developed bottom-up models of reading (Bruning, Schraw, Norby, & Ronning., 2004; Rayner and Pollatsek, 1989). Bottom-up models represent one theoretical model of the reading process focusing on the foundation of phonics and building a repertoire of sight words (Ehri, 1992, 1998, 2005). Ehri explained that, "readers learn sight words by forming connections betweens letters in spellings and sounds in pronunciations of the words" (Ehri, 2005, p. 170). Bottom-up models fail to acknowledge the prior knowledge that the reader brings to the reading task. Additionally, bottom-up models do not explain how reading triggers existing prior knowledge or how comprehension connects new knowledge with old knowledge in long-term memory.

Top-down or conceptually driven models of reading theorize that readers bring meaning to text from prior knowledge and long-term memory. Goodman's top-down model of reading, also called the whole language model, is one of the best-known conceptually driven models (Bruning et al., 2004). Goodman's (1965, 1967, 1994; Goodman & Goodman, 1994) model is based on the observations of children's oral reading errors. Goodman's top-down reading model was seen as concept-driven, where reader's sample text and make predictions based on prior knowledge (Goodman, 1967). The top-down model presented by Goodman is based on four cycles: 1) recognition of visual input; 2) perceptual identification of letters and words; 3) syntactic identification of text structure; and, 4) semantic construction of meaning (Goodman, 1994). Conceptually driven models of reading represent the readers' understanding of the smallest unit in language, phonemes, and build on that knowledge to understand larger structures of language, such as morphemes. Opposite of the bottom-up models, top-down models of reading fail to acknowledge the textual decoding that is sometimes necessary for the reader to make sense of a word, phrase, sentence, or paragraph.

Interactive models of reading posit that the process of reading and comprehension is based on a combination of both bottom-up and top-down processing. Kintsch (1988, 1998) introduced the construction-integration model, an interactive model of reading, to address limitations of the bottom-up and top-down models of reading including the bottom-up models' inability to address the effects of readers' prior knowledge, and top-down models' inability to address the importance of decoding words and phonemic knowledge (Bruning et al., 2004). Kintsch's construction-integration model "focuses on discourse processing (the comprehension of main ideas or themes included in a text) and how meaning is constructed as readers move through the text" (Bruning et. al., p. 265). Interactive models of the reading process incorporate the fundamental tenets of both the bottom-up and top-down models of the reading process.

A significant feature of Kintsch's construction-integration model, an example of an interactive reading model introduced in 1998, is the existence of microstructures and macrostructures. The reader develops microstructures as they moved through the text. They consist of "the propositions generated by the sentence-by-sentence information in the text, plus some information from reader's long-term memories" (Bruning et. al., p. 265). Simultaneously, readers also develop macrostructures, which are structured, hierarchical, and represent the overall meaning of the text. Macrostructures are more difficult to develop in an online reading environment because the readers' path is not controlled comprehensively throughout the text allowing for less structure and ordered hierarchy.

According to Kintsch's construction-integration model, readers develop two types of mental representations of text: textbases and situation models. Textbases are representative of the text "as the author of the text intended it" (Kintsch, 1998, p. 50), and independent of the prior knowledge the reader brings to the reading task. Textbases are more easily developed from paper-based text because the author is in complete control of the structure and order of the content presentation as compared to Internet-based text. Situation models are representative of the combination of the textbase and the long-term memories contributed to the text from the reader, which composes the reader's interpretation of the text. Situation models included readers' long-term memories that were triggered and retrieved during the reading process.

Cognitive Theories that May Support Multimedia Reading Comprehension

Again, reading comprehension is a complicated cognitive process that is further complicated by the addition of multimodal, multimedia content. Cognition is the process that occurs in our mind when we are presented with stimuli that is selected, processed, assigned meaning, and stored in long-term memory. Cognition is an inferential experience that is not directly observable and could be used to describe the process of reading comprehension, acquiring knowledge from visually presented verbal stimuli. Several cognitive theories could be applied to the process of multimedia reading; however, two theories resonated with multimedia learning including cognitive load theory and the cognitive theory of multimedia learning. A discussion of how each of these theories applies to multimedia reading follows.

Cognitive Load Theory

Cognitive load theory was first posited by Sweller (1988) to explain the impact that the limited capacity of working memory had on the learner. Cognitive load theory proposes that due to the limitations of working memory's capacity, demands on the information processing system may exceed the learner's capacity causing cognitive overload, missed stimulus information, and incomplete textbases when completing reading tasks (Figure 4). Multimedia reading environments, which present multiple sources of information in multiple modes, have a great deal of potential to exceed the learner's capacity causing cognitive overload, limiting the ability to create comprehensive textbases and situation models.

The structure of human memory is intrinsic to cognitive load theory. According to Baddeley (1986, 1999), human information processing architecture is composed of three major components: the sensory register, working memory, and long-term memory. The sensory register is where stimulus is received; however, stimulus are not processed or assigned meaning in the sensory register. Working memory has a very limited capacity of approximately 5 to 7 pieces of information or chunks of information. Incoming information is processed in working memory and assigned meaning based on contextual clues and prior knowledge retrieved from long-term memory.   Long-term memory stores knowledge in the form schemas that make connections between related pieces of information. The more connections made within existing schema, the easier the information is retrieved.

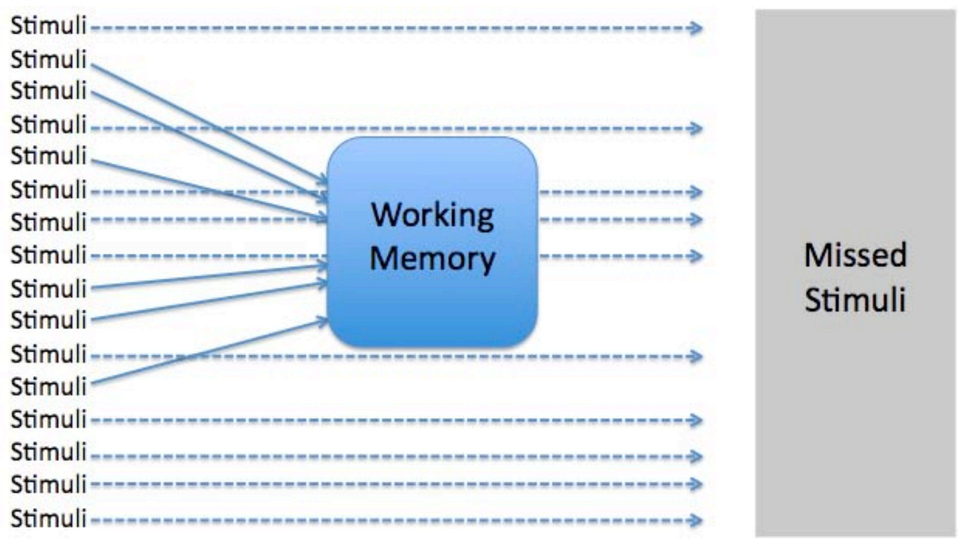


Figure 4. Illustration depicting the overstimulation of working memory causing missed stimuli and cognitive overload.

Cognitive load theory posits that there are three types of cognitive load experienced by learners: intrinsic, extraneous, and germane. Intrinsic cognitive load is based on the inherent difficulty of the topic and is not alterable by the instructional designer or instructor. Extraneous cognitive load is based on how the material is presented and is triggered by superfluous information in the instructional message. The instructional designer can control extraneous cognitive load. Germane cognitive load occurs as the learner engages in relevant processing that builds connections between long-term memory and working memory. Instructional designers can help learners focus on germane processing by reducing extraneous cognitive load. Paas, Renkl, and Sweller (2003) explained, “Intrinsic, extraneous, and germane cognitive loads are additive in that, together, the total load cannot exceed the working memory resources available if learning is to occur” (p. 2). Multimedia learning environments that are designed appropriately could encourage germane processing and discourage extraneous processing.

Reading environments instigate intrinsic cognitive load through vocabulary, sentence, and content complexity. The addition of irrelevant content, both textual and graphical, may stimulate extraneous cognitive load when reading, reducing the comprehension of relevant information. Germane cognitive load in reading environments supports the readers’ construction of macrostructures, microstructures, textbases, and situation models.

Cognitive load theory research has resulted in the identification of detrimental effects related to learning and cognition such as the split attention, redundancy, and modality effects (Sweller, van Merriënboer , & Paas, 1998; van Merriënboer & Ayres, 2005; van Merriënboer & Sweller, 2005). Detrimental cognitive effects could increase extraneous cognitive load and reduce the necessary processing that occurs in germane cognitive load. The split attention effect occurs when the learner has to divide their attention between two sources of information (visual-visual, visual-audible, visual-verbal, verbal-audible) to create a coherent understanding of the presented content. The redundancy effect occurs when identical information (visual and audible text) is presented through multiple modes. The modality effect occurs when information is presented as graphics, visual text, and audible text, which is redundant and could cause split attention effects.

The identification of detrimental cognitive load learning effects has led to better understanding of instructional design approaches and more effective learning environments due to the reduction of extraneous cognitive load, for example, when a learner is presented with complex information that places a high cognitive demand on the learner's working memory, instructional designers can decrease the number of elements that are presented and that require processing in working memory. The learner's cognitive load remains lower and more working memory resources are available for germane processing (Ayres, 2006; Pollock, Chandler, & Sweller, 2002). Reducing extraneous processing and optimizing germane processing optimizes learning and possibly multimedia reading comprehension.

Cognitive load theory and multimedia reading. Cognitive load theory has not only informed the instructional design of learning environments, but has played a valuable role in the design of multimedia learning environments in particular. Multimedia learning environments can have a profound effect on a learner's working memory. Often times, multimedia learning environments contain visual information (both static and active) and verbal information (both printed and audible), used to engage learners. However, the effects of such environments often overload a learner's working memory, dramatically decreasing the learner's ability to process the incoming information and formulate a comprehensive textbase.

Comprehension based on multimedia reading environments, according to Schnotz (2005), "is highly dependent on what kind of information is presented and how it is presented" (p. 49). Schnotz (2005) goes on to say that learning occurs when the learner "uses the external representations as information sources in order to construct in working memory internal (mental) representations of the learning content and he or she stores these representations in long-term memory" (p. 52). Based on Schnotz's explanation, multimedia reading comprehension requires the learner to incorporate both the visually and verbally presented information (Mayer, 1997, 2001; Paivio, 1986).

Levie and Lentz (1982), Levin, Anglin, and Carney (1987), Rivlin, Lewis, and Davies-Copper (1990), and Sweller (1994), through their research, have discovered that graphics that are complex, poorly-designed, and inappropriately labeled or not labeled at all confuse learners, increase their cognitive load, and split their attention between understanding the instructional content and finding and deciphering the included graphics. Therefore, when a learner experiences cognitive overload, they often become frustrated and loose their motivation to continue. When developing multimedia learning environments, it is better to include simple, clear, well-designed graphics that are appropriately labeled.

Additionally, Carney and Levin (2002), Levin et al. (1987), Mayer and Moreno (1998, 2003), Moreno and Mayer (2000), Paas, Renkl, and Sweller (2003), and Schnotz's (2005) multimedia research indicates that extraneous graphics and text should be excluded from instructional material. Mayer's (2009) cognitive theory of multimedia learning's coherence principle states, "People learn better when extraneous material is excluded rather than included" (p. 89). Based on cognitive load theory, extraneous information increases extraneous cognitive processing, limiting the amount of working memory resources dedicated to relevant germane processing.

Furthermore, Sweller's (1994) cognitive load theory explains that graphics should be used to present spatial structures, location, and detail, and words to present logical conditions, and abstract verbal concepts (Lohr, 2008; and Ware, 2000). Organizational graphics can minimize learners' cognitive load by externalizing complex information and off-loading extraneous processing (Tversky, Morrison, & Betrancourt, 2002). Including organizational graphics in multimedia instruction "helps learners understand the structure, sequence, and hierarchy of information and help[s] integrate that information" (Lohr, 2008, p. 18) into long-term memory. Organizational graphics can aid the multimedia learner in developing a comprehensive understanding of the presented material by reducing learners' cognitive load.

Measuring cognitive load. Cognitive load describes the burden that information processing places on working memory. Brunken, Plass, and Leutner (2003) explain, "Although [cognitive load] is well understood as a theoretical construct, the measurement of cognitive load induced by instructional materials in general, and by multimedia instruction in particular, mainly relies on methods that are either indirect, subjective, or both" (p. 53). Direct measures of cognitive load have been elusive to researchers; however, indirect measures have been widely used, especially in the form of self-report multiple-choice questions. Actually measuring quantitatively the amount of cognitive load experienced by a learner has proven difficult.

Brunken et al. (2003) categorize cognitive load measures based on two dimensions: objectivity and causal relationship. Brunken et al. (2003), describes the dimensions as follows:

> The objectivity dimension describes whether the method uses subjective, self-reported data or objective observations of behavior, physiological conditions, or performance. The causal relation dimension classifies methods based on the type of relation of the phenomenon observed by the measure and the actual attribute of interest. (p. 55)

Subjective cognitive load measures are the most readily available and simple to implement, but have been criticized for their ability to actually measure an individual's cognitive load. Objective measures are more costly to implement and have been used in cognitive load theory research for much less time.

Indirect, subjective measures assess cognitive load through self-reports regarding the amount of effort that a learner had to put forth. Paas, van Merriënboer, and Adam (1994) proposed an indirect, subjective cognitive load measure that requires learners to report the amount of effort they expended toward developing an understanding of the presented instructional materials, a technique also used by Paas, Tuovinen, Tabbers, and Van Gerven (2003). Brunken et al. (2003) explains that this indirect, subjective cognitive load measure "appears to be able to assess the subjective perception of invested effort reliably" (p. 56). However, a self-reported small investment of effort could be provided by learners who actually experienced low cognitive load or such a high cognitive load that the learner virtually gave up (Reed, Burton, & Kelly, 1985).

Kalyuga, Chandler, and Sweller (1999) introduced direct, subjective measures to gauge learners' cognitive load. Direct, subjective measures ask participants to rate the difficulty of the presented instructional materials. Although direct, subjective measures such as the reported task difficulty can be highly sensitive (Kalyuga et al., 1999), Brunken et al. (2003) explains that, "these differences could potentially also have been caused by task difficulty, individual competency levels of the learners, or different attentional processes" (p. 57). Direct, subjective measures also have the tendency to be intrusive to the learning activity.

Indirect, objective measures are the most commonly used by cognitive load researchers (Brunken et al., 2003) and are based on performance outcome measures such as knowledge transfer or retention tests. Brunken et al. (2003) explains, "Outcome measures of the learning task are objective because they measure performance. They are indirect because they depend on processes of information storage and retrieval that may be affected by cognitive load" (p. 56). It is hypothesized that the amount of knowledge retained by the learner is directly related to the amount of cognitive load that is experienced by the learner. The results of indirect, objective measures can be challenged by the results of research studies that indicate that learner characteristics such as prior knowledge and spatial ability can also cause differences in learning outcome measurements (Mayer, 2001; Plass, Chun, Mayer, & Leutner, 1998). Additional methods of indirect, objective measures may include physiological characteristics such as: time-on-task, eye-tracking, and heart rate measures.

Direct, objective measures include brain imaging and dual tasks. Brain imaging techniques include positron-emission tomography (PET scans) and functional magnetic resonance imaging (fMRI imaging). These direct, objective measurement techniques are fairly new to cognitive load research and can also be quite costly. Braver, Cohen, Nystrom, Jonides, Smith, and Noll (1997) explain that the application of brain imaging techniques to complex learning processes such as cognitive load are not yet conclusive. However, Callicott et al. indicated a connection between the results of fMRI brain images and working memory limits. Additionally, Brunken et al. (2003) explains:

> The technical complexity of the measurement apparatus and the practical limitations of the duration and frequency of measurements make its use in authentic learning situations difficult. However, once these problems have been overcome, this method may be a potential new approach for the direct, objective measurement of cognitive load in complex learning processes. (p. 56)

Brain imaging technologies show great promise to the field of cognitive load research; however, they can be cost prohibitive and impractical to use as a realistic measure for authentic learning situations.

Dual tasks are another direct, objective method of measuring cognitive load. Dual tasks purposefully expose learners' to primary tasks, the focus of the instructional content, and secondary tasks, a background activity that intentionally increases the learners' cognitive load. Dual tasks force learners to distribute available cognitive resources between the primary and secondary task. Dual tasks have been used in working memory research (Baddeley & Logie, 1999); however, they have seldom been used in the realm of cognitive load research (Chandler & Sweller, 1996; Marcus, Cooper, & Sweller, 1996; Sweller, 1988). Dual tasks also impact the authenticity of the learning environment by intentionally increasing cognitive load to the detriment of learning outcomes.

DeLeeuw and Mayer (2008) investigated cognitive load measurements for three different types of cognitive load: intrinsic, extraneous, and germane (Mayer, 2001; Sweller, 1999). DeLeeuw and Mayer (2008) explained, "it may be possible that some measures are more sensitive to one type of change in cognitive load than to others" (p. 233). They conducted two experiments to determine if different types of cognitive load measures correlated directly with each of the three specific types of cognitive load. The results of DeLeeuw and Mayer's (2008) experiments support the concept that different cognitive load measures are more sensitive to the three different types of cognitive load. To summarize, they found that response times on dual task measures were more sensitive to extraneous cognitive load; embedded effort ratings were more sensitive to intrinsic cognitive load; and overall difficulty ratings were more sensitive to germane cognitive load. Figure 5 provides an overview of DeLeeuw and Mayer's (2008) experiments.

Cognitive load theory has inspired a great deal of research that has greatly informed the field of instructional design. Additionally, a vast amount of research has been conducted to learn how to accurately measure cognitive load. Although ideal measures have not yet been developed, effective measures of cognitive load are within reach, and the measures that are currently used have been shown to inform research about the unique types of cognitive load.

Type of Cognitive Load	Description	Cognitive Load Manipulation Examples	Type of Cognitive Load Measure	Measurement Dimensions
Extraneous	Cognitive processing unrelated to learning based on how instruction is presented	Adding redundant elements to the instructional presentation; Adding unnecessary extraneous information to instructional presentation	Response time to secondary task	Direct, objective
Intrinsic	Inherent difficulty of the topic	Increasing the complexity and reading level of presented text	Mental effort rating scales embedded throughout the presented instruction (*extremely low mental effort* to *extremely high mental effort*)	Indirect, subjective
Germane	Deep cognitive processing that builds connections between long-term memory and working memory called schemata	Reduction of extraneous cognitive load	Overall difficulty rating situated at the end of the instruction (*extremely easy* to *extremely difficult*)	Direct, subjective

Figure 5. Overview of cognitive load measurements investigated by DeLeeuw and Mayer (2008).

The Cognitive Theory of Multimedia Learning

Adult readers are being asked to comprehend more information from Internet-based multimedia reading environments including content management systems, library web sites, and the World Wide Web in general. Cognitive load theory research findings support multimodal instruction that incorporates verbal information in written or narrated format and imaginal information that is static or dynamic. However, web pages that present verbal information in both audio and written format and imaginal information in both static and dynamic format, in addition to hundreds of links and advertisements, can be overwhelming to the reader and have a detrimental effect on an individual's ability to retain and retrieve the presented information.

To address this issue, Mayer proposed the cognitive theory of multimedia learning in 1997. The cognitive theory of multimedia learning "draws on Paivio's (1986; Clark & Paivio, 1991) dual coding theory, Baddeley's (1992) model of working memory, Sweller's (Chandler & Sweller, 1991; Sweller, Chandler, Tierney & Cooper, 1990) cognitive load theory, Wittrock's (1989) generative theory, and Mayer's (1996) SOI model of meaningful learning" (Mayer & Moreno, 1998). Mayer's (1996) SOI model includes the processes of selecting, organizing, and integrating information. Mayer explains his perception and understanding of multimedia learning through the tenets of the cognitive theory of multimedia learning.

According to Mayer's cognitive theory of multimedia learning (2005), the learner processes information cognitively through selection, organization, and integration. The first cognitive process, selection, describes how a learner handles incoming "verbal information to yield a text base" and its application "to incoming visual information to yield an image base" (Mayer & Moreno, 1998, p. 2). Organization, the second cognitive process, describes the process the learner applies to "the word base to create a verbally-based model," (Mayer, 1999, p. 2) and its application "to the image base to create a visually-based model" (Mayer & Moreno, 1998, p. 2). Integration is the third cognitive process, and describes how the "learner builds connections between corresponding events (or states or parts) in the verbally-based model and the visually-based model" (Mayer & Moreno, 1998, p. 2). The process of selection, organization, and integration describes learning in general and reading comprehension more specifically.

In addition to the three cognitive processes that explain multimedia learning, Mayer (2009) included the following 10 principles divided into 3 categories:

1. Principles for reducing extraneous processing in multimedia learning include:
    a. *Coherence principle* explains that people learn better when all extraneous verbal and imaginal information is removed;
    b. *Signaling principle* explains that people learn better when indicators are used to highlight pertinent material and the organizational structure;
    c. *Redundancy principle* explains that people learn better graphics and audible text rather than graphics, audible, and visual text;
    d. *Spatial contiguity principle* explains that it is better for the learner to present words and images close together rather than spaced far apart or separated;
    e. *Temporal contiguity principle* explains that people learn better when corresponding graphics and text are present on the page rather than on multiple successive pages;
2. Principles for managing essential processing in multimedia learning include:
    a. *Segmenting principle* explains that people learn better when multimedia instruction is segmented into user-paced units rather than one continuous unit;

b. *Pre-training principle* explains that people learn better from multimedia instruction when they are introduced to the key names, terms, and main concepts prior to viewing the instruction;

c. *Modality principle* explains that people learn better from graphics and audible text than from graphics and printed text;

3. Principles for fostering generative processing in multimedia learning include:

a. *Multimedia principle* explains that people learn better from graphics and text than from text alone;

b. *Personalization, voice, and image principle* explains that people learn better from multimedia presentations when text is personal and conversational rather than formal.

Mayer (2008) further describes the principles of multimedia learning as essential components that when appropriately applied reduces extraneous processing, manages intrinsic processing, and fosters germane processing.

The application of the cognitive theory of multimedia learning principles to the multimedia reading environment depends on the following factors: 1) the presence of visual text, 2) the presence of graphics, and 3) the necessity to read the visual text; audible text cannot be present because it eliminates the necessity to read the visual text. In addition, some of the principles are inappropriate for a reading comprehension testing environment. For example, the pre-training principle explains that people learn better from multimedia instruction when they are introduced to the key names, terms, and main concepts prior to viewing the instruction. Introducing the key names, terms, and main concepts prior to reading the essay could affect the reading comprehension test scores.

The cognitive theory of multimedia learning principles that may apply to the design of multimedia reading environments include the coherence principle, signaling principle, spatial contiguity principle, temporal contiguity principle, modality principle, and the multimedia principle. Just as Mayer (2009) contends that the use of these cognitive theory of multimedia learning principles will have a positive effect on learning outcomes, it may also be possible that multimedia reading environments designed based on the cognitive theory of multimedia learning principles will have a positive effect on reading comprehension outcomes; however, whether or not the cognitive theory of multimedia learning principles affect multimedia reading comprehension is unknown due to the dearth of research in this area.

Three assumptions of the cognitive theory of multimedia learning. The cognitive theory of multimedia learning maintains three general assumptions (Mayer, 2005). The first, the dual-channel assumption, is based on Paivio (1986) and Baddeley's (1986, 1999) long history of research that supports dual coding theory and the belief that humans' have a visual channel and a verbal channel used for processing incoming information. The top half of Figure 2 represents the verbal channel and the bottom half represents the imaginal channel. Based on the dual-channel assumption, humans have the innate ability to process multimedia information.

The second assumption of the cognitive theory of multimedia learning is the limited capacity assumption, which explains that the two channels, visual and verbal, are limited to processing a small amount of information at one time. This assumption is also based on Baddeley's (1986, 1999) research, but also includes Chandler and Sweller's (1991; Sweller, 1999) research on cognitive load theory. Based on the limited capacity assumption, multimedia learning environments, as well as multimedia reading environments, have a greater chance of increasing cognitive load and overwhelming the information processing system.

The third assumption, the active processing assumption states, “humans actively engage in cognitive processing in order to construct a coherent mental representation of their experiences” (Mayer, 2005, p. 36). According to Mayer (2005), learners create coherent mental representations when they pay attention to the incoming information, when they are able to organize the incoming information in a way that is logical to the learner, and when the learner is able to combine the new information into existing schemata within long-term memory.

As learners participate in multimedia learning, build coherent mental models, and combine the models with existing memories, learners engage three different memory stores: sensory memory, working memory, and long-term memory as described by Baddeley’s information processing model. Learners must engage in five cognitive processes within the three different memory stores for meaningful multimedia learning to occur. Within sensory memory, learners must select relevant words and images. Within working memory, learners must organize selected words and images, and within long-term memory, learners must integrate verbal and imaginal representations of the incoming information. Learners engage in these five processes repeatedly throughout a multimedia presentation of information, not just at the end of the presentation. Extraneous cognitive load can pull the learners’ cognitive resources away from any or all of the five necessary cognitive processes.

The increasing infusion of technology in our communication, information, and instructional activities, in addition to the multimodal emphasis on the presentation of these activities, increases the need for understanding how images are processed, their role in processing information, and how they support the process of learning and comprehension. Clark and Mayer (2003) explain that learners are psychologically at an advantage when instructional materials are presented in such a way that the information engages two different cognitive channels, verbal and imaginal. There is a relationship between the learner's cognitive processing and comprehension and the way information is presented. However, the presentation of more information, verbal or imaginal, does not always result in better learning. Does the psychological advantage described by Clark and Mayer (2003) carry over to the multimedia reading environment?

The cognitive theory of multimedia learning's multimedia principle. The cognitive theory of multimedia learning's multimedia principle is fundamental to all other cognitive theory of multimedia learning principles. The multimedia principle states, "people learn better from words and pictures than from words alone" (Mayer, 2009, p. 223). When learners are presented with both verbal and imaginal information, they most likely will construct a mental model that engages both channels, verbal and imaginal. However, when a learner is presented with verbal information only, they will most likely construct a verbal model only. When both the verbal and the imaginal channels are engaged in a mental model, stored knowledge is connected by more schemata and may be easier to retrieve. Mayer supports the multimedia principle by stating, "In eleven out of eleven tests, learners who received text and illustrations or narration and animation (multiple-representation group) performed better on transfer tests than did learners who received text alone or narration alone (single-representation group). The median effect size was $d = 1.39$" (p. 223). Knowledge transfer tests are significantly different than reading comprehension tests.

Mayer and Anderson (1992) designed an experiment to compare participant performance after receiving instruction that included different combinations of animation and narration: concurrent, animation only, narration only, alternating animation first, alternating narration first, all animation then narration, all narration then animation, and no instruction. The subject matter of the instruction was the function of a bicycle tire pump. When analyzing the retention test results, Mayer and Anderson's statistical analysis detected that the groups significantly differed from one another, $F(7, 128) = 12.25$, $p < .001$. The results of the follow-up Tukey tests indicated that the control group, subjects who did not receive the computerized presentations, scored significantly lower than each of the other groups. The seven treatment groups did not differ from one another. Furthermore, the analysis of variance of the problem solving test scores resulted in group differences, $F(7, 128) = 7.86$, $p < .001$. The follow-up Tukey test revealed that the concurrent group performed significantly better than each of the other groups, which did not differ significantly from one another.

Mayer and Anderson (1992) conducted a second experiment to duplicate experiment one with a different topic, how car-braking systems work. Analysis of variance (ANOVA) revealed that the groups differed significantly from one another, $F(l, 136) = 6.68$, $p < .001$. Further testing, again using Tukey tests, determined that all of the groups except for the animation only group significantly outscored the control group on the retention test. Analysis of the problem solving test scores also revealed that the groups differed significantly from one another, $F(l, 136) = 5.63$, $p < .001$. Follow-up Tukey tests detected that the concurrent group outscored each of the other groups, and all other groups did not differ significantly from one another. The results of both Mayer and Anderson's (1992) experiments support the multimedia principle. Additionally, in two out of the two experiments, the concurrent group, the group that received animation and narration at the same time, outperformed all other groups.

The cognitive theory of multimedia learning's multimedia principle has been tested through outcome measures such as knowledge retention and knowledge transfer. Knowledge retention measures ask participants to list the number of key ideas they can recall from the instruction. Knowledge transfer measures ask participants to solve related but different problems by applying the knowledge they gained from the instruction. Literal reading comprehension measures have not been used as an outcome measure to investigate support for the multimedia principle. Based on existing research, it is currently unknown if the cognitive theory of multimedia learning's multimedia principle applies to reading comprehension environments.

Learner Characteristics that May Affect Multimedia Reading

Learners bring individual attributes to learning environments that make each participant's learning experience unique. These unique characteristics, such as spatial ability and prior knowledge, can impact the effectiveness of every learning environment. The tenets of the cognitive theory of multimedia learning posit that spatial ability and prior knowledge can impact the effectiveness of multimedia learning environments. Both constructs are explored in the following sections.

Spatial Ability

Spatial ability is defined as the ability to construct, manipulate, and maintain visual images in working memory and is categorized as a cognitive skill. Mayer (2005) explained, "The ability to engage in spatial cognition is particularly important in multimedia learning. Conventional instructional messages are heavily verbal, but multimedia messages are verbal and visual – so multimedia learners need to be able to form, hold, and use mental images" (p. 172). As instructional environments move from the classroom to the Internet, more multimedia is presented to potential learners regardless of their cognitive abilities.

Research conducted by Mayer and Sims (1994) and Moreno and Mayer (1999) indicated that high spatial ability learners outperform low spatial ability learners in multimedia environments. Mayer and Sims (1994) conducted two experiments. Experiment one provided multimedia instruction about how braking systems work. Participants were assessed with a knowledge transfer test in which high spatial ability learners outperformed low spatial ability learners by 36%, resulting in an effect size of *d*=.66. Additionally, Mayer and Sims' (1994) second experiment, which provided instruction on the human respiratory system, produced similar results to experiment one. Again, participants were assessed with a knowledge transfer test in which high spatial ability learners outperformed low spatial ability learners by 56%, resulting in an effect size of *d*=1.6. Mayer and Sims' experiments indicate that in multimedia learning environments high spatial ability learners outperform low spatial ability learners on knowledge transfer tests (Figure 6).

High Spatial Ability Learners

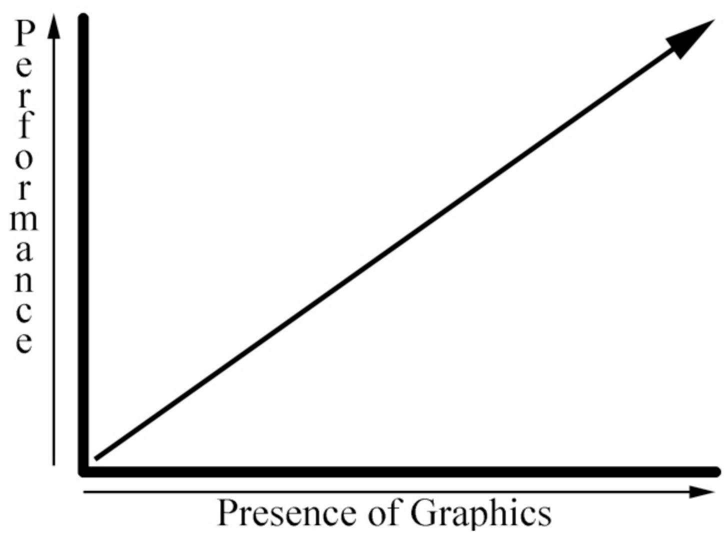


Figure 6. Graph indicating the affect of graphics on performance for high spatial ability learners.

Moreno and Mayer (1999) followed up Mayer and Sims' experiments with further investigation into spatial ability. Moreno and Mayer (1999) exposed two groups of mathematics students to either a single-representation lesson or a multiple-representation lesson. Participants were assessed based on pre-test-to-post-test gain. The results indicated that high spatial-ability students produced a significantly greater pre-test-to-post-test gain than did low spatial-ability students when exposed to the multiple-representation lesson (t (24) = 2.29, $p < .05$). Moreno and Mayer's experiment also indicated that high spatial ability learners outperform low spatial ability learners in multimedia learning environments. However, this experiment focuses on pre-test-to-post-test gain and not direct reading comprehension measures.

Mayer, Moreno, and Sims' research indicates that spatial ability can impact learning in multimedia environments based on indicators of learning. Are their conclusions transferrable to the multimedia reading environment that is assessed through reading comprehension test measures? The results of Mayer, Moreno, and Sims' research imply that spatial ability may impact the multimedia reader as well; however, further research is needed to determine the affect that spatial ability may have on the multimedia reader and their comprehension.

Prior Knowledge

Prior knowledge is defined as "substantial previously acquired knowledge in a specific domain" (Kalyuga, 2005, p. 325). Prior knowledge is an individualized learner characteristic that can aid learners in acquiring additional, more complex knowledge by providing an existing schema structure that new knowledge can be incorporated into. However, there may also be learning environments in which prior knowledge may actually hinder the acquisition of new knowledge (Kalyuga, Chandler, & Sweller, 1998, 2000, 2001). Smith and Ragan (1999) encourage instructional designers to develop a strong understanding of the learners' characteristics because so many individual factors can affect the success of instruction. For example, Rieber (1994) explains, "Visuals are effective some of the time under some conditions" (p. 132). In fact, the effectiveness of visuals often times depends on the learner's prior knowledge (Carney & Levin, 2002).

According to Mayer (2009), Mayer and Sims (1994), and Mayer, Steinhoff, Bower, and Mars (1995), multimedia effects are strongest for low-prior knowledge and high-spatial ability students. Moreno and Mayer (2007) provide more detail by explaining, “students with high prior knowledge may be able to generate their own mental images while listening to an animation or reading a verbal text so having a contiguous visual presentation is not needed” (p. 4). Additionally, Mayer, and Gallini (1990) and Mayer et al. (1995) have found that students with low prior knowledge who are presented instructional material in multimedia format perform better on learning assessments than students with high prior knowledge. Kalyuga, Ayres, Chandler, and Sweller (2003) call this the expertise reversal effect (Figure 7).

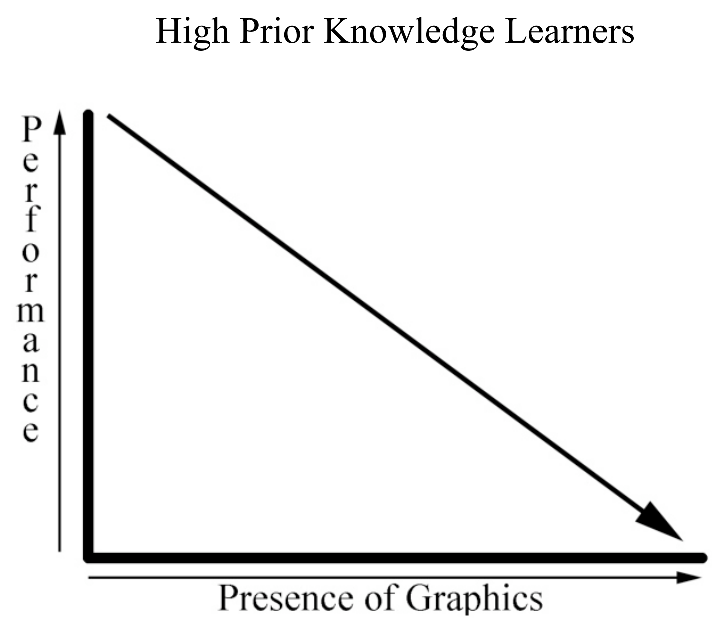


Figure 7. Graph indicating the affect of graphics on performance for high prior knowledge learners.

Kalyuga (2005) explained the expertise reversal effect and how prior knowledge can affect multimedia learning by stating, “as levels of learner knowledge in domain changed, relative effectiveness of different instructional formats reversed" (p. 327). Based on the research of Gyselinck and Tardieu (1999), and Mayer and Gallini (1990), Clark, Lyons, and Hoover (2004) developed a design guideline for learners with low prior knowledge, which states that most low prior knowledge learners "benefit from use of explanatory visual representations of content that are congruent with text because the visual can reduce [cognitive] load and provide a secondary route to forming mental models" (p. 196). Additionally, Clark et al. (2004) also developed a design guideline for high prior knowledge learners based on the research of Kalyuga et al. (2003) and Mayer and Gallini (1990), which stated that high prior knowledge learners, "benefit from either text or visuals alone rather than redundant representations of information" (p. 196).

A great deal of research investigating the expertise reversal effect has been conducted by researches such as: Mayer, Steinhoff, Bower, and Mars (1995) and Kalyuga, Chandler, and Sweller (1998), a body of research that demonstrated support for the expertise reversal effect with percent gain differences ranging from 55% to 180% (Kalyuga, 2005). Mayer et al. (1995) presented the results of a study that investigated the cognitive theory of multimedia learning's contiguity principle. The results of the study demonstrated that presentations that included text and images together rather than separated were better for low prior knowledge learners and not for high knowledge learners.

Kalyuga et al. (1998) conducted a research study in which some participants were exposed to textual explanations that included a great deal of visual detail that was embedded into a wiring diagram, while other participants were exposed to the wiring diagram alone. Kalyuga et al. (1998) explained, "As levels of the [participants] expertise in the domain increased, the relative improvement of performance of the [participants] who learned from the diagram only instructions was superior to those who studied the integrated diagram-and-text instructions" (p. 331). The results of this study also support the integration of text and images for low prior knowledge learners.

Learner characteristics can impact the success of instruction. Prior knowledge and spatial ability are two learner characteristics that have been demonstrated through empirical research to impact learning in multimedia environments. The research that has guided the development of these individual characteristics guidelines has focused on knowledge transfer and retention, similar to much of the cognitive theory of multimedia learning research. Does the research that supports the effect of individual characteristics on multimedia learning translate to multimedia reading comprehension?

The effect of multimedia reading on comprehension. Does multimedia reading affect comprehension? Based on Paivio's (1986) dual coding theory and the cognitive theory of multimedia learning's multimedia principle, the use of multimedia may support reading comprehension by creating more coded connections in long-term memory; however, cognitive load theory (Sweller, 1988, 1999) suggests that the use of multimedia in reading environments may cause cognitive overload by providing too many stimuli for a person to hold in their limited working memory. Mayer and Moreno (2002) explain, "Computer-based multimedia learning environments — consisting of pictures (such as animation) and words (such as narration) — offer a potentially powerful venue for improving student understanding. However, all multimedia messages are not equally effective" (p. 108). Is it possible to create multimedia reading environments that enable more coded connections to be created in long-term memory without overwhelming the limited capacity of working memory?

Chun and Plass (1996) explored the effectiveness of multimedia for second language reading comprehension. They first introduced readers to the overall gist of the text through the use of a visual advanced organizer. Participants who were exposed to the visual advanced organizer included a significantly greater number of topic recall protocols than participants who were not exposed to the visual advanced organizer ($t(101)=7.50$, $p < .001$). Chun and Plass (1996) indicated that their results support the previous visual advance organizer research of Omaggio (1979), Hudson (1982), Taglieber, Johnson, Yarbrough, (1988), and Hanley, Herron, and Cole, (1995). However, the use of visual advanced organizers in multimedia environments focusing on assessing reading comprehension would be inappropriate for traditional reading comprehension testing procedures which makes it impossible to determine if the cognitive theory of multimedia learning's multimedia principle directly applies to multimedia reading environments based on Chun and Plass' (1996) research.

Next, Chun and Plass (1996) explored the effectiveness of multimedia for second language reading comprehension through the use of visual annotations of second language vocabulary words. They reported that the mean for vocabulary words presented without visual annotations ($M = 1.95$) was significantly lower than the vocabulary words presented with visual annotations ($M = 2.32$). Their conclusions support the tenets of the multimedia principle in that information presented visually and verbally results in better comprehension. Additionally, Chun and Plass' (1996) study supports the tenets of the cognitive theory of multimedia learning's multimedia principle in that people learn better when information is presented as text and images rather than just words; however, participants in this study were not asked to complete a reading comprehension test.

Glenberg and Langston (1992) exposed participants to "texts describing four-step procedures in which the middle steps were described as occurring at the same time, although the verbal description of the steps was sequential" (p. 129). Some of the participants read the text only while others read the text combined with graphics. Participants that read the text combined with graphics responded more accurately to a speed-based procedure ordering task than those who read the text only, $F(1, 46) = 14.12$, $p < .001$. Again, this study supports the multimedia principle for learning, but not necessarily for reading comprehension.

Stone and Glock (1981) presented three groups with instructions for completing an assembly task; group 1 read the text with illustrations, group 2 read the text only, and group 3 viewed the illustrations only. Data analysis indicated a significant difference between the three groups based on the number of errors that occurred during the assembly task ($p < .0005$). Further analysis revealed that group 1 participants who read text with illustrations made significantly fewer errors than participants in group 2 ($p < .001$) and group 3 ($p < .001$). However, the results of assembly tasks do not necessarily correlate with reading comprehension test measures.

Based on the experiments presented, there is clearly support for the application of the cognitive theory of multimedia learning's multimedia principle in learning tasks. There is, however, very little research that investigates the use of the multimedia principle in reading comprehension environments. One would assume that if the multimedia principle supports learning for the completion of tasks or the ordering of procedures that it would also support reading comprehension; however, there is virtually no empirical evidence to support this assumption. Indeed, research that investigates the application of the multimedia principle to reading comprehension environments is needed.

Summary of Related Literature

This literature review identified a plethora of research that has been conducted around the cognitive theory of multimedia learning and cognitive load theory. The cognitive models of reading comprehension including bottom-up, top-down, and interactive were thoroughly described to provide a foundation of understanding to be used in the interpretation of the multimedia learning research that was summarily presented. Cognitive theories including cognitive load theory and the cognitive theory of multimedia learning were presented in detail. Additionally, learner characteristics that may affect multimedia reading comprehension were identified including spatial ability and prior knowledge. The problem is that very little of the research has focused on the measure of reading comprehension; the focus has been on knowledge retention, knowledge transfer, task completion, multimedia learning, and the principles of the cognitive theory of multimedia learning.

Is the cognitive theory of multimedia learning applicable to multimedia reading comprehension? Is the formulation of textbases and situation models effected by multimedia? The overall purpose of this literature review was to investigate what is known about multimedia learning and its application to multimedia reading environments that, in turn, will support reading comprehension. Currently, these questions are unanswered. Further research into the application of the cognitive theory of multimedia learning principles is indicated to enable researchers to answer these questions.

CHAPTER 3

METHODS

The preceding chapters suggested that designing multimedia reading environments based on the cognitive theory of multimedia learning's multimedia principle may support reading comprehension for Internet-based multimedia readers; however, existing research has investigated the use of the cognitive theory of multimedia learning for knowledge retention and transfer rather than reading comprehension. Therefore, the purpose of this study was to test the applicability of the cognitive theory of multimedia learning's multimedia principle to the design of multimedia reading environments based on reading comprehension test scores. This study also aimed to examine the relationship between readers' comprehension in text only and multimedia environments in relation to their prior knowledge, spatial ability, and self-reported cognitive load. The following research questions framed this study:

1. Do reading comprehension scores differ between readers who read text-only essays and readers who read the graphics and text essays?
2. Do reading comprehension scores differ between questions that are directly related to included graphics and questions that are indirectly related to included graphics?
3. Do multimedia reading environments affect readers' self-reported cognitive load?
4. Does a reader's self-reported cognitive load change based on spatial ability?
5. Does a reader's reading comprehension test scores change based on the reader's prior knowledge?
6. Does a reader's cognitive load change based on the reader's prior knowledge?

7. Does a reader's reading comprehension scores change based on the reader's spatial ability?
8. Does a reader's reading comprehension test scores change based on the reader's cognitive load?

Research Design

The cognitive theory of multimedia learning's multimedia principle posits that people learn better from graphics and text than from text alone. To investigate whether this described multimedia effect occurs in multimedia reading environments, this research study employed an experimental design with two randomly assigned treatments: 1) *text-only*, where the reading comprehension essay is presented in text only format; and 2) *multimedia*, where the reading comprehension essay is presented in multimedia format including text and related graphics.

The Experimental Treatment

Participants were randomly assigned to one of two experimental treatments, text only or multimedia, through the implementation of a JavaScript that randomly generated a website address to one of the data collection instruments (See Appendix A). The participants assigned to the text only group read an Internet-based essay on color theory that was formatted only with visual text. No graphics were included (See Appendix B). The participants assigned to the multimedia group read an Internet-based essay on color theory that included related images in its formatting. Eight content related graphics were included (See Appendix C). Learner characteristics that have potential to effect learning outcomes from multimedia environments including spatial ability, prior knowledge, and cognitive load, were also assessed. Following the completion of the online data collection process, each participant had 4 scores, 1 for each of the following measures: prior knowledge, spatial ability, reading comprehension, and cognitive load.

Research Context

Undergraduate students who were enrolled in courses at a large public research university in the southeast United States were asked to participate in this study. Participants were asked to individually complete the data collection process including demographic data questions, the spatial ability test, prior knowledge test, a randomly assigned text only or multimedia color theory essay, a reading comprehension test, and cognitive load self-report. Participants were also asked to complete the data collection process independently, just as they would complete any other Internet-based reading assignment.

Participants

Participants included volunteer undergraduate students who were enrolled in courses at a large public research university in the southeastern United States during the spring 2010 semester. Undergraduate courses were selected from the university's *Schedule of Classes*, which also identified the course instructors. Course selection criteria included the following:

1. The course was offered during the spring 2010 semester
2. The course had an identifiable course instructor (class instructor was not listed as Staff)
3. The course number was 5999 or less.

Undergraduate course instructors were initially contacted via email (see Appendix D). The email explained to instructors that, if time permitted, the researcher was available to come to class to introduce the study face-to-face. However, if time did not permit, the initial instructor email also included a student email that could easily be forwarded to student email accounts. Follow-up reminder emails were sent to instructors that did not respond to the initial email approximately two weeks following the initial contact date (see Appendix E). See the participant recruitment flowchart in Figure 8.

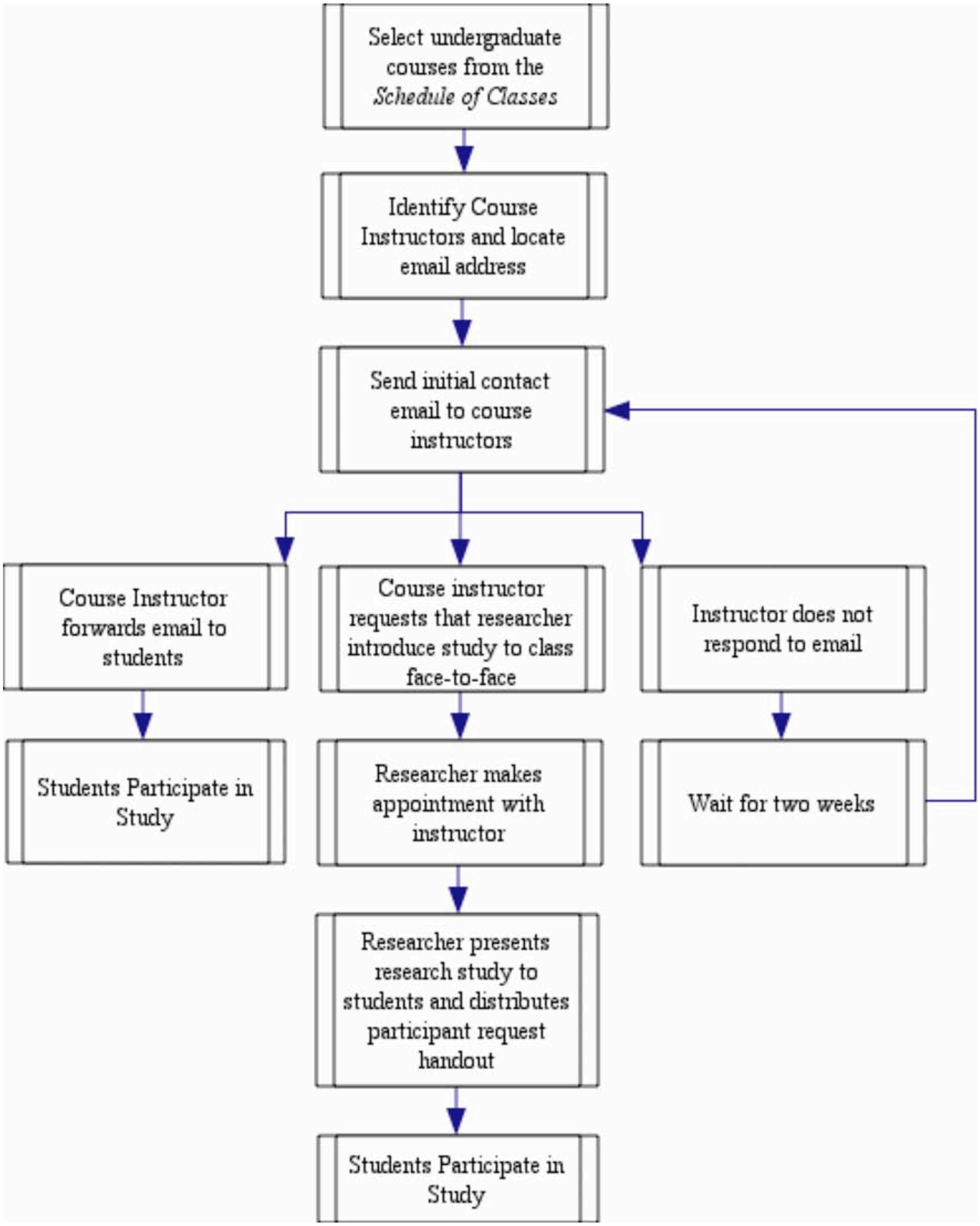


Figure 8. Participant recruiting flowchart.

To determine an appropriate sample size, *G*Power*, a general power analysis program authored by Buchner, Faul, and Erdfelder, was used as an a priori analysis tool. The hypothesis tested was a two-tailed test with the error rate value of α =.05. The anticipated effect size is medium (.50) and the power was predicted to be .80. Based on these criteria, it was determined that the approximate sample size should have been 51 participants per treatment group or a total of 102 participants.

Data Collection Instruments

The data collection instruments were available participants and included: an electronic consent form, prior knowledge test, spatial ability test, reading comprehension test, and a cognitive load self-report questionnaire. All data collection instruments were hosted through a professional SurveyMonkey account owned by the researcher. A description for each data collection instrument follows. See Figure 9 for an overview of the data collection instruments.

Electronic consent form. For ease of use and since all of the data collection instruments were Internet-based, participants digitally signed an online consent form by selecting the "I would like to participate in this research study" option (see Appendix F). If participants decided not to participate after reading the consent form, they selected the "I choose NOT to participate in this research study" option, they were thanked for their time and the data collection window was closed.

Demographic Data Collection. Participants were asked to complete the demographic data page requesting that they submit their age and their gender (see Appendix G). The demographic information requested of the participants was for the purpose of describing the participant sample population only.

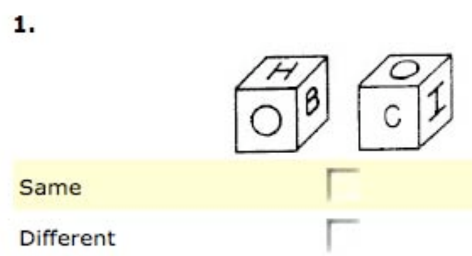
Instrument	Construct Measure	Number of Items	Sample Item
Prior Knowledge Test	Prior Knowledge	3	1. The primary colors on a traditional color wheel include: (provide as many answers as you can think of up to 3)
Cube Rotation Test from the ETS Kit of Factor-Referenced Cognitive Tests	Spatial Ability	10	Please decide if the pairs of cubes could be the same or if they are different and mark your choice below the image. Remember: No letters, numbers, or symbols appear on more than one face of a given cube. 
Reading Comprehension Test	Reading Comprehension	20	5. Colors that are mixed with black are called ________. • shades • shadows • blends • tints • tones
Cognitive Load Self-report	Cognitive Load	2	1. How difficult was it to read the color theory article? • Very High Difficulty • High Difficulty • Moderate Difficulty • Low Difficulty • Very Low Difficulty

Figure 9. Summary of data collection instruments.

Prior knowledge test. The prior knowledge test consisted of three fill-in-the-blank questions that asked specifically about color theory knowledge. The first question asked participants to provide the names of the primary colors on a traditional color wheel. Three blanks were provided to participants for this question. The second question asked participants to determine what could be added to a color to change its value. Two blanks were provided for the second question. The third question asked participants to provide the names of common color schemes. Five blanks were provided for question three. Each correct answer provided by participants earned one point. A total of 10 points were possible for the prior knowledge test. The prior knowledge test can be found in Appendix H.

The first pilot study included a prior knowledge measure that consisted of three self-report questions. The pilot study prior knowledge assessment was evaluated for reliability using Cronbach's Alpha. The result was $\alpha = .695$, a somewhat acceptable measure of reliability. However, the self-report measures used to determine the level of color theory prior knowledge each participant had was subjective. Following the data analysis of the pilot study, the researcher determined that a direct measure of prior knowledge would be more accurate than the subjective self-report measure used in the pilot study. The self-report questions were discarded and the three fill-in-the-blank color theory questions were developed to directly measure an individual's prior knowledge of color theory.

The second pilot study collected sample data to evaluate the reliability of the new prior knowledge test. Thirty-two participants completed the prior knowledge test. The reliability measure calculated for the prior knowledge assessment was calculated using Cronbach's Alpha. The result was $\alpha = .749$, an acceptable measure of reliability.

Spatial ability test. The Educational Testing Service's (ETS) Kit of Factor-Referenced Cognitive Tests was selected to assess participants' spatial ability. Permission to use the cube comparisons test for this research study was granted by ETS' Research and Development department in July 2009 (see Appendix I). Four paragraphs of instruction were provided to help participants understand the requirements of the cube comparisons test. Additionally, participants were provided with two practice questions (see Appendix J). Following the page of instructions, participants were asked to complete 10 cube comparison questions that were part of the Educational Testing Service's Kit of Factor-Referenced Cognitive Tests. The selected questions were used to assess the participants' spatial orientation. The spatial ability test can be found in Appendix K.

The pilot study consisted of two separate spatial ability tests from the ETS Kit of Factor-Referenced Cognitive Tests. The first section, the card rotation test, included a page of instructions with 6 practice problems followed by 9 scored card rotation problems. The mean score for the 9 scored problems was $M = 8.54$ with a standard deviation of $SD = .95$. The reliability measure for the card rotation test calculated using Cronbach's Alpha was $\alpha = .531$.

The second section, the cube rotation test, included a page of instructions including 2 practice problems followed by 6 scored cube rotation problems. The mean score for the 6 scored problems was $M = 4.0$ with a standard deviation of $SD = 1.0$. The reliability measure for the cube rotation test calculated using Cronbach's Alpha was $\alpha = .459$. The overall mean and standard deviation for the spatial ability tests based on a composite score calculated by adding the card rotation and cube comparison scores together was $M = 12.89$, $SD = 1.87$. The reliability measure calculated using Cronbach's Alpha was $\alpha = .551$. The reliability measures for the spatial ability tests used in the pilot study were not satisfactory.

The spatial ability test was revised and sample data were collected in pilot test two. To reduce the amount of time that participants spent on the spatial ability test, the card rotation test portion was eliminated. The card rotation test was discarded because participants tended to score consistently high and the results did not successfully differentiate participants. Additionally, time on task was reduced since participants only had to read one set of instructions. To improve the reliability of the spatial ability measure, additional questions were added to the cube rotation test.

The second pilot study collected sample data to evaluate the reliability of the new prior knowledge test. Thirty-two participants completed the prior knowledge test. Ten cube rotation comparison questions were included in the spatial ability test. The resulting Cronbach's Alpha was α = .739, an acceptable measure of reliability.

Color theory essay. The color theory essay, which was authored by the researcher, provided readers with a brief history of the development of the traditional color wheel, historical figures that had contributed to the field of color theory, fundamental concepts of the color wheel, and existing color relationships and schemes. There were 2 versions of the color theory essay, 1 for each treatment. The essay consisted of 368 words, 22 sentences, and 6 paragraphs. Based on the Gunning-Fog Index developed by Robert Gunning in 1952, the color theory essay has a reading level of 14.95, indicating that a college sophomore or junior would have completed the appropriate number of years of formal education to easily understand the essay. Additionally, the Flesch-Kincaid readability test, developed in 1976, resulted in a reading level of 12.22 indicating that a college freshman could read and understand the essay. Based on the results of the Gunning-Fog and the Flesch-Kincaid readability tests, the color theory essay is considered appropriate reading for undergraduate college students.

Following the initial pilot test, further analysis was conducted on the color theory essay regarding length, the Flesch-Kincaid reading level, and the Gunning-Fog reading level. An Internet search through *Google* was conducted to find the top ten color theory websites containing essays on the topic. Analysis of each of the ten essays was conducted to determine their word count, Flesch-Kincaid reading level, and the Gunning-Fog reading level See Table 1 for the results of the analysis.

The mean for the length of the ten sample essays was $M = 1517.8$ while the standard deviation was $SD = 1010.34$, a rather large standard deviation. The mean Flesch-Kincaid reading level for the ten sample essays was $M = 10.85$ with a standard deviation was $SD = 2.45$. Additionally, the Gunning-Fog reading level for the ten sample essays was $M = 12.41$ with a standard deviation was $SD = 2.07$. Based on this analysis the color theory essay that participants were required to read was revised.

The final version of the essay contained 1,038 words, less than the ten sample essays' mean; however, it was within the limits of the standard deviation and in consideration of participants, it took less time to read. Furthermore, the Flesch-Kincaid reading level for the data collection essay was 11.04 and the Gunning-Fog reading level was 13.06, both within the limits of the sample essays' standard deviations. The data collection essay was representative of a typical color theory essay found on the Internet.

Reading comprehension test. The reading comprehension test was developed to assess the readers' ability to recall information provided in the color theory essay. The reading comprehension test used for the pilot study consisted of eight multiple-choice questions. The reliability of the reading comprehension test was analyzed using the pilot test data resulting in a Cronbach's Alpha of $\alpha = -.223$. A negative Cronbach's Alpha is indicative of a set of questions measuring different dimensions.

Table 1

Color Theory Essay Reading Analysis

Color Theory Essay	Word Count	Flesch-Kincaid Reading Level	Gunning-Fog Reading Level	URL
1	702.00	10.75	14.56	http://www.colormatters.com/colortheory.html
2	3085.00	15.87	14.77	http://en.wikipedia.org/wiki/Color_theory
3	1110.00	7.29	8.74	http://colortheory.liquisoft.com
4	832.00	9.87	11.36	http://www.tigercolor.com/color-lab/color-theory/color-theory-intro.htm
5	676.00	10.39	12.52	http://www.color-wheel-pro.com/color-theory-basics.html
6	1128.00	11.03	12.63	http://www.cs.brown.edu/courses/cs092/VA10/HTML/ColorModels.html
7	1348.00	8.59	10.70	http://www.wetcanvas.com/ArtSchool/Color/ColorTheory/Lesson2/index.html
8	3508.00	10.54	12.07	http://www.wetcanvas.com/ArtSchool/Color/ColorTheory/Lesson4/index.html
9	871.00	10.27	11.31	http://www.valcasey.com/webdesign/color.html
10	1918.00	13.91	15.47	http://www.colorcube.com/articles/basics/basics.htm
Mean	1517.80	10.85	12.41	
SD	1010.34	2.45	2.07	

Based on the results of the pilot data reliability analysis, the reading comprehension test questions were reevaluated and redeveloped to ensure a direct connection with the color theory essay. The new questions were tested during the second pilot study. The revised test consisted of 27 multiple-choice questions, each having 5 possible answers. The multiple-choice questions were taken directly from the text of the color theory essay. All of the questions were fill-in-the-blank. Participants were provided five key words or phrases to choose from to complete the sentences. See Figure 10 for examples of the comprehension questions.

The second pilot study collected sample data to evaluate the reliability of the new reading comprehension test. Thirty-two participants completed the reading comprehension test, which included twenty-seven questions. Question 4 and 7 were immediately eliminated because all participants answered them correctly and they added no variability. The resulting Cronbach's Alpha based on the remaining 25 questions was $\alpha = .844$, an acceptable level; however, a 25 question reading comprehension test might have taken too much of the participants' time and cause them to prematurely quit. Using the results of the reliability analysis, 5 additional questions were eliminated, including questions 1, 10, 21, 23, 24, resulting in a Cronbach's Alpha of $\alpha = .878$. See Table 2 for detailed information regarding the reading comprehension test item removal.

The final version of the reading comprehension test contained 20 multiple-choice questions. Each question provided the participant with a blank and five words or phases to choose from to fill in the blank. The final version of the reading comprehension test can be found in Appendix L.

Color Theory Essay Text	Reading Comprehension Sample Question	Possible Answers
Based on these color relationships and schemes, the traditional color wheel is used by artists and painters to guide the process of mixing paints, dyes, and inks.	1. Based on color relationships and schemes, the traditional color wheel is used by artists and painters to guide the process of _________ paints, dyes, and inks.	• gradating • identifying • exploring • *mixing* • juxtaposing
Colors that are mixed with white are called tints.	5. Colors that are mixed with white are called ________.	• shadows • blends • tones • shades • *tints*
Complementary color schemes include two colors that are directly opposite of one another on the color wheel.	15. Complementary color schemes include two colors that are ____________ on the color wheel.	• subordinate • adjacent • neighbors • *opposite* • dominant

Figure 10. Color theory essay text, related comprehension questions, and the five possible multiple-choice answers (the correct answer is italicized).

Table 2

Reliability Analysis for Reading Comprehension Test Item Removal

Item Eliminated	Original Cronbach's Alpha	Resulting Cronbach's Alpha	Number of Items Remaining
Question 4	-	α=.844	26
Question 7	-	α=.844	25
Question 21	α=.844	α=.855	24
Question 23	α=.855	α=.862	23
Question 1	α=.862	α=.867	22
Question 10	α=.867	α=.873	21
Question 24	α=.873	α=.878	20

Cognitive Load Self-Report. The cognitive load self-report was a direct, subjective measure (see Appendix M). The self-report measure asked participants two questions:

1) How difficult was it to read the color theory article?

2) How difficult was it to answer the reading comprehension questions?

The two cognitive load self-report questions were also used in the pilot study. Correlational analysis was conducted on these two questions as part of the pilot study. The result was $r = .727$, indicating a strong relationship between the two questions, suggesting that they are measuring the same construct, cognitive load. Additionally, the cognitive load measures were analyzed for reliability. The pilot test data analysis of the cognitive load measures resulted in a Cronbach's Alpha of $\alpha = .838$, an acceptable level of reliability.

The second pilot study also collected sample data on the cognitive load self-report measures. Thirty-two participants completed the cognitive load self-report measures. The second pilot test resulted in much different results. The Pearson correlation between the 2 questions result was $r = .180$, a very low correlation, much different than the resulting correlation from the first pilot study. The pilot test data analysis of the cognitive load measures resulted in a Cronbach's Alpha of $\alpha = .292$, an unacceptable level of reliability.

The cognitive load measure was thoroughly supported in the related literature as was demonstrated in Chapter 2. Additionally, the first pilot study resulted in an acceptable Cronbach's Alpha. Therefore, it was determined that the cognitive load measure would remain in the data collection instrument without modification.

Data Collection Procedures

Data collection began by selecting undergraduate courses from the university's *Schedule of Classes*, which also identified the course instructors. Through the university's website search feature and departmental websites, course instructor emails were collected. Undergraduate course instructors were initially contacted via email. The initial email provided a brief explanation of the research study and invited the instructor to either forward the email to their students or, if time permitted, the instructor invited the researcher to come to class to introduce the study face-to-face. When requested by the course instructor, the researcher spent five minutes during class time to introduce the research study. Following the five-minute introduction of the study, the researcher handed out volunteer recruitment flyers to each student (see Appendix N). Follow-up reminder emails were sent to instructors that did not respond to the initial email approximately two weeks following the initial contact date.

Students who chose to participate were randomly assigned to a treatment group through a randomization JavaScript that produced a web link for the participant to follow. The JavaScript was programmed to pick between two links, one that sent participants to the text only data collection instrument and one that sent participants to the text and graphics data collection instrument. Once participants were assign to a treatment group, they were asked to digitally sign the online consent form before beginning the study. They completed the consent process by selecting the "I would like to participate in this research study" option. If students chose the "I choose NOT to participate in this research study" option, they were thanked for their time and the data collection window was closed (see Appendix O).

Participants were then asked to provide basic demographic information including their age and gender. The collected demographic data was collected to describe the sample only and was not included in the guiding research questions or the final data analysis.

The second section of the data collection process was the prior knowledge test. The purpose of the prior knowledge test was to gauge the participants' familiarity with the essay topic, color theory. The prior knowledge test consisted of three fill-in-the-blank questions that asked specifically about color theory. A total of 10 points were possible on the prior knowledge test.

The third section of the data collection process included the spatial intelligence test. The spatial intelligence test used in this study was licensed through the Educational Testing Service (ETS) and included one test found in the Kit of Factor-Referenced Cognitive Tests, the S-2 Cube Comparison Test. Directions for the S-2 Cube Comparison Test were presented to participants along with two practice questions. The directions page was followed by the actual S-2 Cube Comparison Test including 10 questions.

After completing the prior knowledge test, participants were asked to read the color theory essay. Participants who were assigned to the text only group read the essay formatted with text only. Participants who were assigned to the multimedia group read the essay formatted with text and graphics.

Next, participants are asked to complete the reading comprehension test. Both of the treatment groups, text only and multimedia were asked the same reading comprehension questions. The reading comprehension test consisted of 20 questions. There were no images included with the reading comprehension questions.

After participants completed the reading comprehension questions, they were asked to self-report how difficult it was to read the color theory essay and answer the reading comprehension questions. The self-report difficulty questions were used to gauge the cognitive load experienced by the participants.

Data Analysis Procedures

Four phases of data analysis followed the data collection procedures: description, analysis of covariance, correlation, and reliability. Data gathered from the online reading comprehension test including the demographic data, prior knowledge test, spatial ability test, reading comprehension test, and cognitive load self-report were analyzed for descriptive purposes. Data collected through the online instruments were evaluated using analysis of covariance and correlation. Furthermore, each data collection instrument was evaluated for reliability. Participants who failed to answer all questions included in the data collection instruments were eliminated from the data set.

Descriptive Analysis

Demographic data. A descriptive analysis using the Statistical Package for the Social Sciences (SPSS) version 16.0 for Mac was conducted. Descriptive statistics such as mean and standard deviation were used to describe the sample population's age. A descriptive analysis of gender was also conducted to determine the proportion of the population that was male and to determine the proportion of the population that was female.

Prior knowledge test. A descriptive analysis was conducted on the prior knowledge test measure to determine the mean and standard deviation of the test results. Analysis was conducted on participants' composite scores, which were determined by totaling the number of correct answers provided for each of the three prior knowledge questions. Using the composite scores, the mean and standard deviation were used to describe the prior knowledge test results.

Spatial ability test. A descriptive analysis was conducted on the spatial ability test measure to determine the mean and standard deviation of the test results. Analysis was conducted on participants' composite scores, which were determined by totaling the number of correct answers provided for each of the 10 spatial ability questions. Using the composite scores, the mean and standard deviation were used to describe the spatial ability test results.

Reading comprehension test. A descriptive analysis was conducted on the reading comprehension test measure to determine the mean and standard deviation of the test results. Analysis was conducted on participants' composite scores, which were determined by totaling the number of correct answers provided for each of the 20 reading comprehension questions. Using the composite scores, the mean and standard deviation were used to describe the reading comprehension test results.

Cognitive load self-report. A descriptive analysis was conducted on the cognitive load self-report measure to determine the mean and standard deviation of the reported results. Analysis was conducted on participants' composite scores, which were determined by totaling the level of cognitive load reported by participants' for each of the cognitive load questions (Table 3). Using the composite scores, the mean and standard deviation were used to describe the cognitive load self-report results.

Table 3

Cognitive load questions, available responses, and corresponding scores.

Question 1	Available Response and Corresponding Score		Question 2	Available Response and Corresponding Score	
How difficult was it to read the color theory article?	Very High Difficulty	5	How difficult was it to answer the reading comprehension questions?	Very High Difficulty	5
	High Difficulty	4		High Difficulty	4
	Moderate Difficulty	3		Moderate Difficulty	3
	Low Difficulty	2		Low Difficulty	2
	Very Low Difficulty	1		Very Low Difficulty	1

Analysis of Covariance

Analysis of covariance (ANCOVA) using SPSS version 16.0 for Mac was conducted. ANCOVA was used to investigate the between group differences (text only and multimedia). The dependent variable was reading comprehension and the covariates were spatial ability, prior knowledge, and cognitive load. The ANCOVA was used to answer the following research questions:

1. Do reading comprehension scores differ between readers who read text-only essays and readers who read the graphics and text essays?
2. Do reading comprehension scores differ between questions that are directly related to included graphics and questions that are indirectly related to included graphics?

ANCOVA was also used to investigate the between group differences (text only and multimedia). The dependent variable was cognitive load and the covariates were spatial ability, prior knowledge, and reading comprehension. The ANCOVA was used to answer the following research question:

3. Do multimedia reading environments affect readers' self-reported cognitive load?

Correlational Analysis

Correlational analysis using SPSS version 16.0 for Mac was conducted to investigate the relationships between the variables in this study including: the treatment variables (text only and multimedia), the dependent variable (reading comprehension scores), and the independent variables (spatial ability, prior knowledge, and cognitive load). The correlational analysis was used to answer the following research questions:

4. Does a reader's self-reported cognitive load change based on spatial ability?
5. Does a reader's reading comprehension test scores change based on the reader's prior knowledge?
6. Does a reader's cognitive load change based on the reader's prior knowledge?
7. Does a reader's reading comprehension scores change based on the reader's spatial ability?

8. Does a reader's reading comprehension test scores change based on the reader's cognitive load

Figure 11 summarizes the data analysis procedures used in this study to answer the research questions.

The Pilot Studies

Pilot Study One

The first pilot study for this research project was conducted during the summer of 2009. The purpose of conducting the pilot study was threefold: 1) to test the data collection instruments; 2) to uncover any issues with the initial research design; and 3) to determine if the data collection procedures were appropriate. The overall research question that framed the pilot study was: Does the *cognitive theory of multimedia learning* apply to the design of multimedia reading environments?

Pilot study data collection process. Participants were recruited by contacting undergraduate course instructors via email. The email asked instructors to either forward an included email to their students or to contact the researcher to present the opportunity in person. Several face-to-face presentations were made in student courses and participant recruitment flyers were handed out in person.

Volunteer student participants were directed to a website that randomly assigned them to 1 of 8 treatment groups through a randomization java script. The eight treatment groups included: (1) text only; (2) text with contiguous images; (3) text with extraneous images; (4) text with preceding images; (5) text with following images; (6) text with inline images; (7) text with images at the end of the essay; and, (8) text with signaling.

Research Question	Data Type	Variables	Data Analysis Procedure
1. Do reading comprehension scores differ between readers who read text-only essays and readers who read the graphics and text essays?	Quantitative Experimental Design	Dependent: Reading Comprehension Test Scores Covariates: Prior Knowledge, Spatial Ability, Cognitive Load	ANCOVA
2. Do reading comprehension scores differ between questions that are directly related to included graphics and questions that are indirectly related to included graphics?	Quantitative Experimental Design	Dependent: Reading Comprehension Test Scores Covariates: Prior Knowledge, Spatial Ability, Cognitive Load	ANCOVA
3. Do multimedia reading environments affect readers' self-reported cognitive load?	Quantitative Experimental Design	Dependent: Cognitive Load Covariates: Prior Knowledge, Spatial Ability, Reading Comprehension Test Scores	ANCOVA
4. Does a reader's self-reported cognitive load change based on spatial ability?	Quantitative Experimental Design	Cognitive Load and Spatial Ability	Correlational Analysis
5. Does a reader's reading comprehension test scores change based on the reader's prior knowledge?	Quantitative Experimental Design	Reading Comprehension Test Scores and Prior Knowledge	Correlational Analysis
6. Does a reader's cognitive load change based on the reader's prior knowledge?	Quantitative Experimental Design	Cognitive Load and Prior Knowledge	Correlational Analysis
7. Does a reader's reading comprehension scores change based on the reader's spatial ability?	Quantitative Experimental Design	Reading Comprehension Test Scores and Spatial Ability	Correlational Analysis
8. Does a reader's reading comprehension test scores change based on the reader's cognitive load?	Quantitative Experimental Design	Reading Comprehension Test Scores and Cognitive Load	Correlational Analysis

Figure 11. Summary of research questions and data analysis methods.

Participants were asked to read a consent form and select the appropriate choice regarding their participation in the study: "I would like to participate in this research study" or "I choose NOT to participate in this research study." If participants chose the "I choose NOT to participate in this research study" option, they were sent to a thank you page. If participants chose the "I would like to participate in this research study" option, they were sent to the first data collection page where participants were asked to provide their age and their gender.

The second section of the data collection process included the spatial intelligence test. The spatial intelligence tests used in the pilot study were licensed through the Educational Testing Service (ETS) and included two tests found in the Kit of Factor-Referenced Cognitive Tests: S-1 Card Rotation Test and the S-2 Cube Comparison Test. Overall, 15 spatial intelligence questions were included.

The third section of the data collection process included a prior knowledge self-report questionnaire. Three questions were provided for participants to gauge their familiarity with the essay topic, color theory. The three questions were:

1. How many art related courses have you taken in high school or college?
2. How familiar are you with color theory?
3. How familiar are you with the color wheel?

The next section of the data collection process engaged the participants in reading the color theory essay. Depending on which group participants were assigned, one of the following reading passages was presented to the participant: (1) text only (control group); (2) text with contiguous images; (3) text with extraneous images; (4) text with preceding images; (5) text with following images; (6) text with inline images; (7) text with images at the end of the essay; and, (8) text with signaling. The text was consistently the same from one treatment to another; however, the formatting was different for each.

Regardless of the reading passage format, all participants were asked to answer the same eight reading comprehension questions; each question was grounded in color theory literature. After participants completed the eight reading comprehension questions, they were asked to report how difficult it was to read the color theory essay and answer the reading comprehension questions.

Pilot study data analysis. Pilot study data were analyzed using correlational analysis and ANOVA to gain understanding of the relationships and differences that existed between treatment groups, reading comprehension test scores, prior knowledge, spatial ability, and cognitive load. However, due to the large number of treatment groups and the small number of participants, differences were difficult to detect. It was determined that the breadth of the research design was too cumbersome and that the focus of the study needed to be narrowed.

Suggestions for improving the study.

Narrow the focus of the study. The scope of the pilot study was clearly too broad to truly gain an in depth understanding of all applicable elements of the cognitive theory of multimedia learning to the multimedia reading environment. Therefore, the focus of the study was been greatly narrowed. The focus of the study was reduced to test only one principle of the cognitive theory of multimedia learning, the multimedia principle.

Simplify the spatial ability assessment. Most of the participants that abandoned the pilot research study before completion did so during the spatial ability test. To alleviate this phenomenon, the spatial ability test was simplified by discarding the card rotation test altogether and increasing the number of questions included in the cube comparisons test.

Revise the prior knowledge test. The prior knowledge measure for the pilot study was subjective in that it asked participants to rate their own knowledge. Participants scored themselves on three measures: number of art related courses taken, knowledge of color theory and knowledge of the color wheel. The prior knowledge test was redesigned so that the resulting measure would be more objective.

Pilot Study Two

The second pilot study was conducted during the fall of 2009. The purpose of conducting the second pilot study was to refine and further test the data collection instruments. The overall research question that framed the second pilot study was: Does the cognitive theory of multimedia learning's *multimedia principle* apply to the design of multimedia reading environments? The results of pilot study two were used to further refine the data collection instruments.

CHAPTER 4

RESULTS

The primary purpose of this study was to explore the effects of Internet-based multimedia reading environments on reading comprehension, specifically focusing on the cognitive theory of multimedia learning's multimedia principle. This research study attempted to answers the question, "Do multimedia reading environments designed based on the cognitive theory of multimedia learning's *multimedia principle* affect readers' reading comprehension?" The study also considered the impact that individual learner characteristics such as prior knowledge, spatial ability, and cognitive load may have had on the outcome variable, the reading comprehension test score.

Analysis of Data

Participants

Participants in the study included 233 undergraduate students from a large research university in the southeast United States, 189 female and 44 male. The overall average age of the 233 participants was $M = 20.68$ ($SD = 2.24$). Group 1, the text only group, consisted of 113 total participants whose average age was $M = 20.86$ ($SD = 2.27$). One participant in Group 1 failed to record their age. Group 2, the text and graphics group, consisted of 120 participants whose average age was $M = 20.52$ (SD=2.21). Additionally, Group 1 consisted of 86 females and 27 males while Group 2 consisted of 103 females and 17 males. Table 4 presents an overview of the participants' age and gender and Table 5 presents the summary data, including the means, standard deviations, and the Cronbach's Alpha reliability measure for the dependent variable (reading comprehension score) and the covariate variables (prior knowledge, spatial ability, and cognitive load) overall and by group.

Table 4

Participant Age and Gender Overall and by Group

	All Participants			Group 1 (Text Only)			Group 2 (Text and Graphics)		
Age	N	$\overline{X}$	SD	N	$\overline{X}$	SD	N	$\overline{X}$	SD
	233	20.68	2.24	112	20.86	2.27	120	20.52	2.21
Gender	N	Female	Male	N	Female	Male	N	Female	Male
	233	189	44	113	86	27	120	103	17

Evaluating Assumptions of Analysis of Covariance

Analysis of Covariance (ANCOVA) was used to test the hypotheses for several of the research questions; therefore, the assumptions of ANCOVA were tested first. Assumption one for ANCOVA states that the collected data came from a normally distributed population. To test assumption one, the Shapiro–Wilk normality test was used to evaluate variations from normality. Shapiro–Wilk statistical values that are closer to zero are evidence of variations from the normal distribution. The Shapiro-Wilk statistics calculated for Group 1, the text only group, ranged from .84 to .948, all of which were found statistically significant at the α=.01 level. The Shapiro-Wilk statistics calculated for Group 2, the text and graphic group, ranged from .877 to .949, all of which were found statistically significant at the α=.01 level. Based on these results, we can assume that the data collected for the dependent variable and the covariates significantly depart from normality within groups (Table 6). Since the assumption of normality is violated, it may be more difficult to detect between group differences.

Table 5

Summary Table of Means and Standard Deviations, and Reliability Measures Overall and by Group

	Group 1 (Text Only)			Group 2 (Text and Graphics)		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Prior Knowledge Test Scores	113	4.32	1.63	120	3.91	1.49
Cronbach's Alpha		α=.66			α=.53	
Spatial Ability Test Scores	113	7.14	1.95	120	6.95	2.07
Cronbach's Alpha		α=.57			α=.60	
Reading Comprehension Test Scores	113	14.53	4.19	120	14.85	3.84
Cronbach's Alpha		α=.84			α=.81	
Direct Questions: Reading Comprehension Test Scores	113	7.76	2.61	120	7.98	2.60
Cronbach's Alpha		α=.75			α=.77	
Indirect Questions: Reading Comprehension Test Scores	113	6.77	1.96	120	6.88	1.63
Cronbach's Alpha		α=.70			α=.53	
Self-reported Cognitive Load	113	5.14	1.43	120	5.14	1.57
Cronbach's Alpha		α=.61			α=.71	

Table 6

Calculated results for the Shapiro-Wilk Test of Normality Within Groups

	Shapiro-Wilk Test of Normality					
	Group 1 (Text Only)			Group 2 (Text and Graphics)		
	Statistic	df	Sig.	Statistic	df	Sig.
Prior Knowledge Test Scores	.925	113	.000	.909	120	.000
Spatial Ability Test Scores	.924	113	.000	.941	120	.000
Reading Comprehension Test Score	.913	113	.000	.877	120	.000
Reading Comprehension Test Score: Direct Questions	.921	113	.000	.922	120	.000
Reading Comprehension Test Score: Indirect Questions	.840	113	.000	.914	120	.000
Cognitive Load Scores	.948	113	.000	.949	120	.000

The second assumption of ANCOVA, the assumption of homogeneity of variance, was evaluated second. Levene's Test, which tests for equal variance between samples, was used to evaluate the homogeneity of variances for the dependent variable and the covariates. The results of Levene's Tests determined that there was insufficient evidence at the α=.05 level to reject the null hypothesis that there is a difference between the variances in the population for the prior knowledge test scores, spatial ability test scores, reading comprehension test scores, reading comprehension test scores direct questions, and cognitive load scores. The results of Levene's Tests for the indirect reading comprehension test questions scores, $W(1, 231) = 3.780$, p = .053, was not statistically significant at the α=.05. The null hypothesis of equal variances was supported, resulting in the conclusion that there was no significant difference between the variances in the population for indirect reading comprehension test questions scores. The results of the Levene's Test of Homogeneity of Variances are summarized in Table 7.

Table 7

Calculated results for the Levene's Test of Homogeneity of Variances

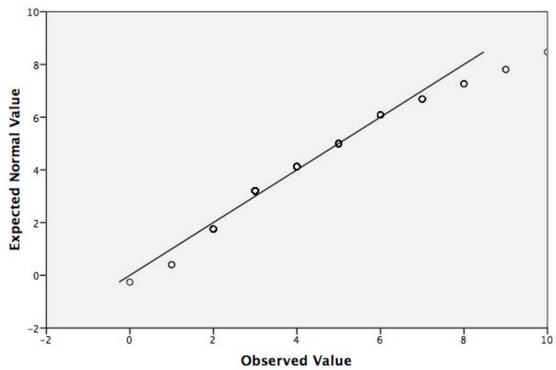
	Levene Statistic	df1	df2	Sig.
Prior Knowledge Test Scores	.872	1	231	.351
Spatial Ability Test Scores	.816	1	231	.367
Reading Comprehension Test Score	.792	1	231	.374
Reading Comprehension Test Score: Direct Questions	.037	1	231	.849
Reading Comprehension Test Score: Indirect Questions	3.780	1	231	.053
Cognitive Load Scores	.178	1	231	.674

The third assumption of ANCOVA presumes that the data is representative of a random sample and that the scores for the dependent variables are independent from one another. Based on the sampling plan presented in *Chapter 3*, it can be assumed that the participants in the study represent a volunteer or self-selected sample of undergraduate students from a large university in the southeast United States. Furthermore, unless data were collected in a strictly controlled environment, it is difficult to assume that the dependent variables are independent from one another. The data were evaluated for duplicate scores on the dependent and covariate variables and no duplicate responses were found; however, the lack of duplicate responses does not guarantee variable independence. Although the statistical accuracy of the ANCOVA may be compromised, we will assume that the dependent variables are independent from one another.

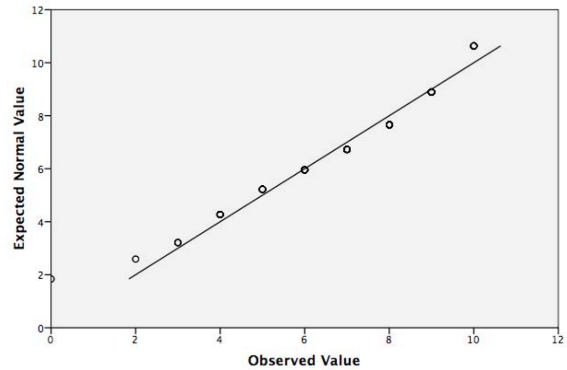
Homogeneity of slopes is the final assumption of ANCOVA. The homogeneity of slopes assumption presumes that the relationship between the covariate and the dependent variable do not differ significantly between groups. The homogeneity of slopes assumption was tested individually for each research question, the results of which were presented with each questions' data analysis results.

Evaluation of Data for Outliers

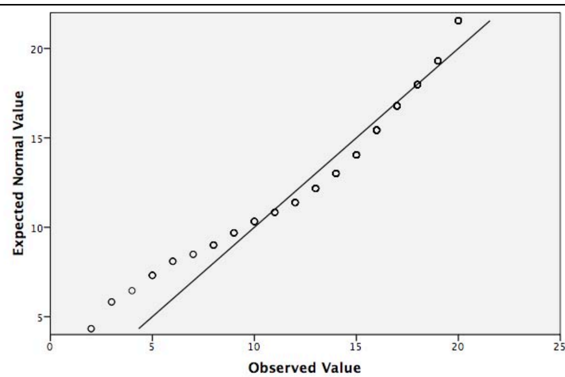
Analysis of Covariance (ANCOVA) was used to test the hypotheses for several of the research questions. The ANCOVA statistical procedure is sensitive to extreme outliers. The ANCOVA calculations with data that includes outliers can result in Type II errors – failure to reject a null hypothesis when it is false. Therefore, all collected data were evaluated for outliers. Evaluation of data for outliers was conducted using normal quantile-quantile plots (Q-Q plot) (Figure 12), which is the plot of the observed values against the expected values of the normal distribution. The points on a Q-Q plot should lie close to a straight line. Most of the extreme values are associated with perfect scores on one of the tests included in the study. Since it would be expected that some individuals would attain a perfect score on a multiple-choice test, none of the indicated outliers were deleted from the study.



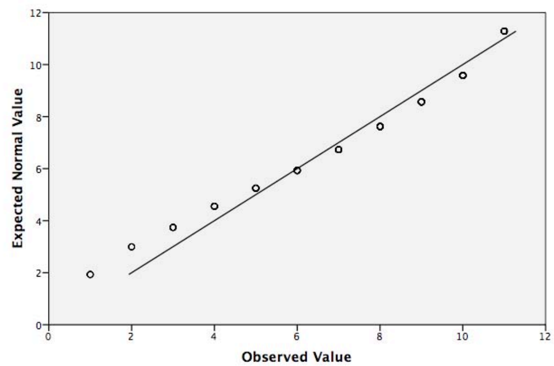
Q-Q Plot for Prior Knowledge Test Scores



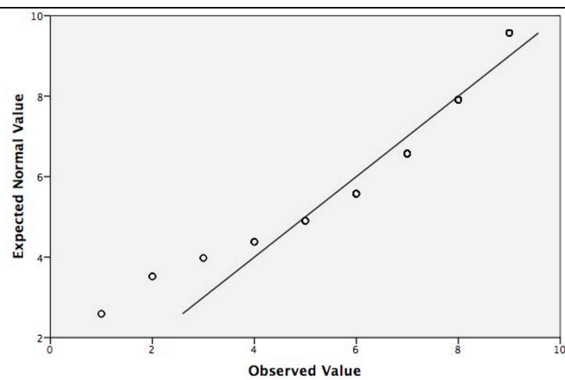
Q-Q Plot for Spatial Ability Test Scores



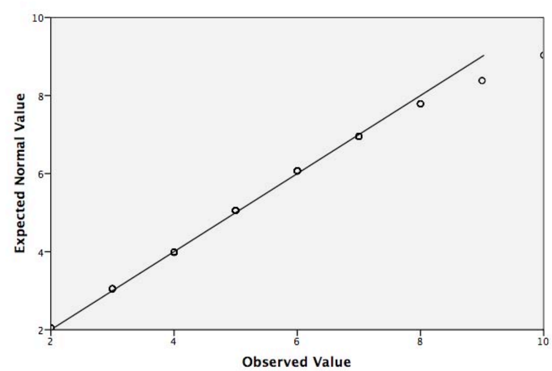
Q-Q Plot for Reading Comprehension Scores



Q-Q Plot for Reading Comprehension Score: Direct Questions



Q-Q Plot for Reading Comprehension Score: Indirect Questions



Q-Q Plot for Cognitive Load Score

Figure 12. Analysis of outliers using Quantile-Quantile plots for dependent and covariate variables.

Research Questions

Research Question #1: Do reading comprehension scores differ between readers who read text-only essays and readers who read graphics and text essays?

Hypothesis #1: Undergraduate students who read in text only environments will score lower on reading comprehension tests than undergraduate students who read in environments that include both text and graphics.

Analysis of covariance (ANCOVA) was conducted to determine whether the inclusion of graphics affects a reader's reading comprehension test scores as compared to readers who read in a text only environment. The covariates used in this analysis included prior knowledge, spatial ability, and cognitive load. The text only group correlation coefficient for prior knowledge and reading comprehension test scores was $r = .258$, the coefficient for spatial ability and reading comprehension test scores was $r = .382$, and the coefficient for cognitive load and reading comprehension test scores was $r = -.517$. All correlation coefficients for the text only group were significant at the $\alpha = .01$ level. The text and graphics group correlation coefficient for prior knowledge and reading comprehension test scores was $r = .189$, the coefficient for spatial ability and reading comprehension test scores was $r = .297$, and the coefficient for cognitive load and reading comprehension test scores was $r = -.585$. The correlation coefficient for prior knowledge was significant at the α=.05 level, while the coefficients for spatial ability and cognitive load were significant at the α=.01 level. A summary of the Pearson correlations is presented in Table 8. To answer research question 1, 3 ANCOVAs were conducted, 1 for each covariate included in the study.

Table 8

Correlations between Reading Comprehension Test Scores and the covariates for each group

	Reading Comprehension Test Score			
	Text Only Group		Text and Graphics Group	
	r	*p*	*r*	*p*
Prior Knowledge Test Score	.258	.006	.189	.039
Spatial Ability Test Score	.382	.000	.297	.001
Cognitive Load Score	-.517	.000	-.585	.000

Do reading comprehension scores differ between groups when controlling for prior knowledge?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, prior knowledge, and the dependent variable, reading comprehension test scores, did not differ significantly between groups, $F(1, 229) = .29$, $p = .593$, partial $\eta^2 = .001$ (Table 9). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment did not significantly affect the reader's reading comprehension scores when controlling for prior knowledge, $F\ (1, 230)=1.16$, and $p=.283$, $\eta^2 = .005$. There was insufficient evidence at the $\alpha=.025$ level to reject the null hypothesis that the text only group will score lower on the reading comprehension test than text and graphics group when controlling for prior knowledge. The results of the ANCOVA were summarized in Table 10.

Table 9

Test of Homogeneity of Slopes for Between-group Prior Knowledge Scores with Reading Comprehension Scores as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4391.93	1	4391.93	285.54	.000	.555
Group * Prior Knowledge Test Score	4.41	1	4.41	.29	.593	.001
Group	11.99	1	11.99	.78	.378	.003
Prior Knowledge Test Score	184.75	1	184.75	12.01	.001	.050
Error	3522.32	229	15.38			
Total	54038.00	233				

Table 10

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable Reading Comprehension Test Scores Controlling for the Covariate Prior Knowledge Scores

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4390.05	1	4390.05	286.30	.000	.555
Prior Knowledge Test Score	188.71	1	188.71	12.31	.001	.051
Group	17.75	1	17.75	1.16	.283	.005
Error	3526.73	230	15.33			
Total	54038.00	233				

Do reading comprehension scores differ between groups when controlling for spatial ability?

Similar to the statistical analysis, which used spatial ability as the covariate, the assumption of homogeneity-of-slopes was again evaluated first. The results indicated that the relationship between the covariate, spatial ability, and the dependent variable, reading comprehension test scores, did not differ significantly between groups, $F(1, 229) = 1.21$, $p = .273$, partial $\eta^2 = .005$ (Table 11). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment do not significantly affect the reader's reading comprehension when controlling for spatial ability, $F(1, 230) = .81$, $p = .368$, $\eta^2 = .004$. Again, there was insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in reading comprehension between students who read text only and students who read text and graphic essays when controlling for spatial ability. The results of the ANCOVA were summarized in Table 12.

Table 11

Test of Homogeneity of Slopes for Between-group Spatial Ability Test Scores with Reading Comprehension Scores as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1671.410	1	1671.41	116.89	.000	.338
Group	24.31	1	24.31	1.70	.194	.007
Spatial Ability Test Score	436.20	1	436.20	30.51	.000	.118
Group * Spatial Ability Test Score	17.29	1	17.29	1.21	.273	.005
Error	3274.39	229	14.30			
Total	54038.00	233				

Table 12

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable Reading Comprehension Test Scores Controlling for the Covariate Spatial Ability Test Score

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1725.21	1	1725.21	120.55	.000	.344
Spatial Ability Test Score	423.76	1	423.76	29.61	.000	.114
Group	11.65	1	11.65	.81	.368	.004
Error	3291.68	230	14.31			
Total	54038.00	233				

Do reading comprehension scores differ between groups when controlling for self-reported cognitive load?

Once again, the assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, self-reported cognitive, and the dependent variable, reading comprehension test scores, did not differ significantly between groups, $F(1, 229) = .08$, $p = .773$, $\eta^2 = .000$ (Table 13). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment did not significantly affect the reader's reading comprehension when controlling for self-reported cognitive, $F(1, 230) = .53$, and $p = .469$, $\eta^2 = .002$. There was insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in reading comprehension between students who read text only and students who read text and graphic essays when controlling for self-reported cognitive load. The results of the ANCOVA were summarized in Table 14.

Table 13

Test of Homogeneity of Slopes for Between-group Cognitive Load Self-reports with Reading Comprehension Scores as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	8918.83	1	8918.83	788.65	.000	.775
Group	.07	1	.07	.01	.940	.000
Cognitive Load Self-reports	1115.55	1	1115.55	98.64	.000	.301
Group * Cognitive Load Self-reports	.94	1	.94	.08	.773	.000
Error	2589.74	229	11.31			
Total	54038.00	233				

Table 14

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable Reading Comprehension Test Scores Controlling for the Covariate Cognitive Load Self-reports

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	9024.46	1	9024.46	801.19	.000	.777
Cognitive Load Self-reports	1124.76	1	1124.76	99.86	.000	.303
Group	5.93	1	5.93	.53	.469	.002
Error	2590.68	230	11.26			
Total	54038.00	233				

Summary of research question #1. Overall, there was insufficient evidence at the α=.05 level to reject the null hypothesis that there is no difference in reading comprehension between students who read text only essays and students who read text and graphic essays when controlling for prior knowledge, spatial ability, or self-reported cognitive load. Based on the three ANCOVA tests, the inclusion of graphics in online reading environments did not affect the outcome of reading comprehension tests.

Research Question #2: Do reading comprehension scores differ between questions that are directly related to included graphics and questions that are indirectly related to included graphics?

Hypothesis #2: Undergraduate students who are assigned to the graphics and text group will score higher on the reading comprehension questions that are directly related to included graphics than undergraduate students who are assigned to the text only group, but the scores for the reading comprehension questions that are indirectly related to included graphics will not differ between the text only and text and graphics groups.

Analysis of covariance (ANCOVA) was conducted to determine whether the text only group or the text and graphics groups scored higher on the reading comprehension questions that were directly related to included graphics in the text and graphics treatment and whether the text only group or the text and graphics group scored higher on the reading comprehension questions that were indirectly related to included graphics in the text and graphics treatment. The covariates used in this analysis included prior knowledge, spatial ability, and cognitive load. Pearson correlations were calculated within groups for each of the covariates and the reading comprehension questions that were directly related to the included graphics and indirectly related to the included graphics.

The text only group correlation coefficient for prior knowledge and reading comprehension questions that were directly related to the included graphics was $r = .276$, the coefficient for spatial ability and reading comprehension questions that were directly related to the included graphics was $r = .328$, and the coefficient for cognitive load and reading comprehension questions that were directly related to the included graphics was $r = -.480$. All text only group correlation coefficients for reading comprehension questions that were directly related to included graphics were significant at the $\alpha = .01$ level.

The text only group correlation coefficient for prior knowledge and reading comprehension questions that were indirectly related to the included graphics was $r = .183$, the coefficient for spatial ability and reading comprehension questions that were indirectly related to the included graphics was $r = .379$, and the coefficient for cognitive load and reading comprehension questions that were indirectly related to the included graphics was $r = -.466$. The text only group correlation coefficient between spatial ability and the dependent variable reading comprehension questions that were indirectly related to the included graphics was significant at the $\alpha = .05$ level and the text only group correlation coefficients between cognitive load and the dependent variable reading comprehension questions that were indirectly related to the included graphics was significant at the $\alpha = .01$ level. However, the text only group correlation coefficient between prior knowledge and reading comprehension questions that were indirectly related to the included graphics was not statistically significant. Table 15 summarizes the text only group correlation coefficient.

The text and graphics group correlation coefficient for prior knowledge and reading comprehension questions that were directly related to the included graphics was $r = .184$, the coefficient for spatial ability and reading comprehension questions that were directly related to the included graphics was $r = .316$, and the coefficient for cognitive load and reading comprehension questions that were directly related to the included graphics was $r = -.570$. The text and graphics group correlation coefficients between spatial ability and cognitive load and the dependent variable reading comprehension questions that were directly related to the included graphics were significant at the $\alpha = .01$ level. The text and graphics group correlation coefficient between prior knowledge and reading comprehension questions that were directly related to the included graphics was statistically significant at the $\alpha = .05$ level.

Table 15

Text Only Group Correlations between Reading Comprehension Scores for Questions that are Directly and Indirectly Related to Included Graphics and the Covariates Prior Knowledge, Spatial Ability, and Cognitive Load

	Prior Knowledge Test Score		Spatial Ability Test Score		Self-reported Cognitive Load	
	r	*p*	*r*	*p*	*r*	*p*
Reading Comprehension Scores for Questions Directly Related to Included Graphics	.276	.003	.328	.000	-.480	.000
Reading Comprehension Scores for Questions Indirectly Related to Included Graphics	.183	.053	.379	.000	-.466	.000

The text and graphics group correlation coefficient for prior knowledge and reading comprehension questions that were indirectly related to the included graphics was $r = .151$, the coefficient for spatial ability and reading comprehension questions that were indirectly related to the included graphics was $r = .195$, and the coefficient for cognitive load and reading comprehension questions that were indirectly related to the included graphics was *r* = -.469. The text and graphics group correlation coefficient between prior knowledge and reading comprehension questions that were indirectly related to the included graphics was not statistically significant. The text and graphics group correlation coefficient between spatial ability and reading comprehension questions that were indirectly related to the included graphics was significant at the α = .05 level and the text and graphics group correlation coefficient between cognitive load and reading comprehension questions that were indirectly related to the included graphics was significant at the α = .01 level. Table 16 summarizes the text and graphics group correlation coefficients. To answer research question 2, 6 ANCOVAs were conducted, 3 for reading comprehension questions that were directly related to the included graphics with each covariate included in the study, and 3 for reading comprehension questions that were indirectly related to the included graphics with each covariate included in the study.

Table 16

Text and Graphics Group Correlations between Reading Comprehension Scores for Questions that are Directly and Indirectly Related to Included Graphics and the Covariates Prior Knowledge, Spatial Ability, and Cognitive Load

	Prior Knowledge Test Score		Spatial Ability Test Score		Self-reported Cognitive Load	
	r	*p*	*r*	*p*	*r*	*p*
Reading Comprehension Scores for Questions Directly Related to Included Graphics	.184	.044	.316	.000	-.570	.000
Reading Comprehension Scores for Questions Indirectly Related to Included Graphics	.151	.099	.195	.033	-.469	.000

Directly related questions.

Do scores for reading comprehension questions that are directly related to included graphics differ between groups when controlling for prior knowledge?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, prior knowledge, and the dependent variable, scores for reading comprehension question that are directly related to included graphics, did not differ significantly between groups, $F(1, 229) = .33$, $p = .569$, $\eta^2 = .001$ (Table 17). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment do not significantly affect the reader's reading comprehension when controlling for prior knowledge, F(1, 230) = 1.23, p = .269, $\eta^2 = .005$. There is insufficient evidence at the α = .025 level to reject the null hypothesis that the students who are assigned to the graphics and text group will score higher on the reading comprehension questions that are directly related to included graphics than undergraduate students who are assigned to the text only groups when controlling for prior knowledge. The results of the ANCOVA are summarized in Table 18.

Table 17

Test of Homogeneity of Slopes for Between-group Prior Knowledge with Reading Comprehension Scores as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Group	5.57	1	5.57	.86	.355	.004
Prior Knowledge Test Score	81.68	1	81.68	12.61	.000	.052
Group * Prior Knowledge Test Score	2.11	1	2.11	.33	.569	.001
Error	1483.88	229	6.48			
Total	16008.00	233				

Table 18

ANCOVA Summary Table Testing for Group Differences on the dependent variable Reading Comprehension Test Scores controlling for the Covariate Prior Knowledge

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1143.89	1	1143.89	177.05	.000	.435
Prior Knowledge Test Score	83.49	1	83.49	12.92	.000	.053
Group	7.93	1	7.93	1.23	.269	.005
Error	1485.99	230	6.46			
Total	16008.00	233				

Do scores on reading comprehension questions that are directly related to included graphics differ between groups when controlling for spatial ability?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, spatial ability, and the dependent variable, scores on reading comprehension questions that are directly related to included graphics, did not differ significantly between groups, $F(1, 229) = .08$, $p = .785$, $\eta^2 = .000$ (Table 19). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment do not significantly affect the reader's reading comprehension when controlling for spatial ability, $F\ (1, 230) = .82$, and $p = .366$, $\eta^2 = .004$. There is insufficient evidence at the $\alpha = .025$ level to reject the null hypothesis that the students who are assigned to the graphics and text group will score higher on the reading comprehension questions that are directly related to included graphics than undergraduate students who are assigned to the text only groups when controlling for spatial ability. The results of the ANCOVA are summarized in Table 20.

Table 19

Test of Homogeneity of Slopes for Between-group Spatial Ability with the Dependent Variable, Scores for Reading Comprehension Questions that are Directly Related to Included Graphics

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	416.79	1	416.79	67.85	.000	.229
Group	1.59	1	1.59	.26	.611	.001
Spatial Ability	162.51	1	162.51	26.46	.000	.104
Group * Spatial Ability	.46	1	.46	.08	.785	.000
Error	1406.69	229	6.14			
Total	16008.00	233				

Table 20

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable, Scores for Reading Comprehension Questions that are Directly Related to Included Graphics, Controlling for the Covariate, Spatial Ability

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	424.196	1	424.196	69.335	.000	.232
Spatial Ability Score	162.326	1	162.326	26.532	.000	.103
Group	5.010	1	5.010	.819	.366	.004
Error	1407.148	230	6.118			
Total	16008.000	233				

Do scores on reading comprehension questions that are directly related to included graphics differ between groups when controlling for cognitive load?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, cognitive load, and the dependent variable, scores on reading comprehension questions that are directly related to included graphics, did not differ significantly between groups, $F(1, 229) = .12$, $p = .734$, $\eta^2 = .001$ (Table 21). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment did not significantly affect the reader's reading comprehension when controlling for cognitive load, $F(1, 230) = .54$, and $p = .463$, $\eta^2 = .002$. There is insufficient evidence at the $\alpha = .025$ level to reject the null hypothesis that the students who are assigned to the graphics and text group will score higher on the reading comprehension questions that are directly related to included graphics than undergraduate students who are assigned to the text only groups when controlling for cognitive load. The results of the ANCOVA are summarized in Table 22.

Table 21

Test of Homogeneity of Slopes for Between-group Cognitive Load Self-reports with the Dependent Variable, Scores for Reading Comprehension Questions that are Directly Related to Included Graphics

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2834.15	1	2834.15	573.46	.000	.715
Group	1.39	1	1.39	.28	.596	.001
Cognitive Load	426.58	1	426.58	86.31	.000	.274
Group * Cognitive Load	.57	1	.57	.12	.734	.001
Error	1131.76	229	4.94			
Total	16008.00	233				

Table 22

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable, Scores for Reading Comprehension Questions that are Directly Related to Included, Controlling for the Covariate, Cognitive Load Self-reports

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2884.43	1	2884.43	585.89	.000	.718
Cognitive Load	437.14	1	437.14	88.79	.000	.279
Group	2.67	1	2.67	.54	.463	.002
Error	1132.34	230	4.92			
Total	16008.00	233				

Indirectly related questions.

Do scores on reading comprehension questions that are indirectly related to included graphics differ between groups when controlling for prior knowledge?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, prior knowledge, and the dependent variable, scores on reading comprehension questions that are indirectly related to included graphics, did not differ significantly between groups, $F(1, 229) = .13$, $p = .715$, $\eta^2 = .001$ (Table 23). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment did not significantly affect the reader's reading comprehension when controlling for prior knowledge, $F(1, 230) = .62$, and $p = .432$, $\eta^2 = .003$. There is insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in reading comprehension scores between students who read essays with text only and students who read essays with text and graphics for questions that are indirectly related to included graphics when controlling for prior knowledge. The results of the ANCOVA are summarized in Table 24.

Table 23

Test of Homogeneity of Slopes for Between-group Prior Knowledge with the Dependent Variable, Scores for Reading Comprehension Questions that are Indirectly Related to Included Graphics

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1052.356	1	1052.356	333.060	.000	.593
Group	1.219	1	1.219	.386	.535	.002
Prior Knowledge Test Score	20.745	1	20.745	6.566	.011	.028
Group * Prior Knowledge Test Score	.421	1	.421	.133	.715	.001
Error	723.561	229	3.160			
Total	11596.000	233				

Table 24

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable, Scores for Reading Comprehension Questions that are Indirectly Related to Included Graphics, Controlling for the Covariate, Prior Knowledge

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1052.10	1	1052.10	334.24	.000	.592
Prior Knowledge Test Score	21.16	1	21.16	6.72	.010	.028
Group	1.95	1	1.95	.62	.432	.003
Error	723.98	230	3.15			
Total	11596.00	233				

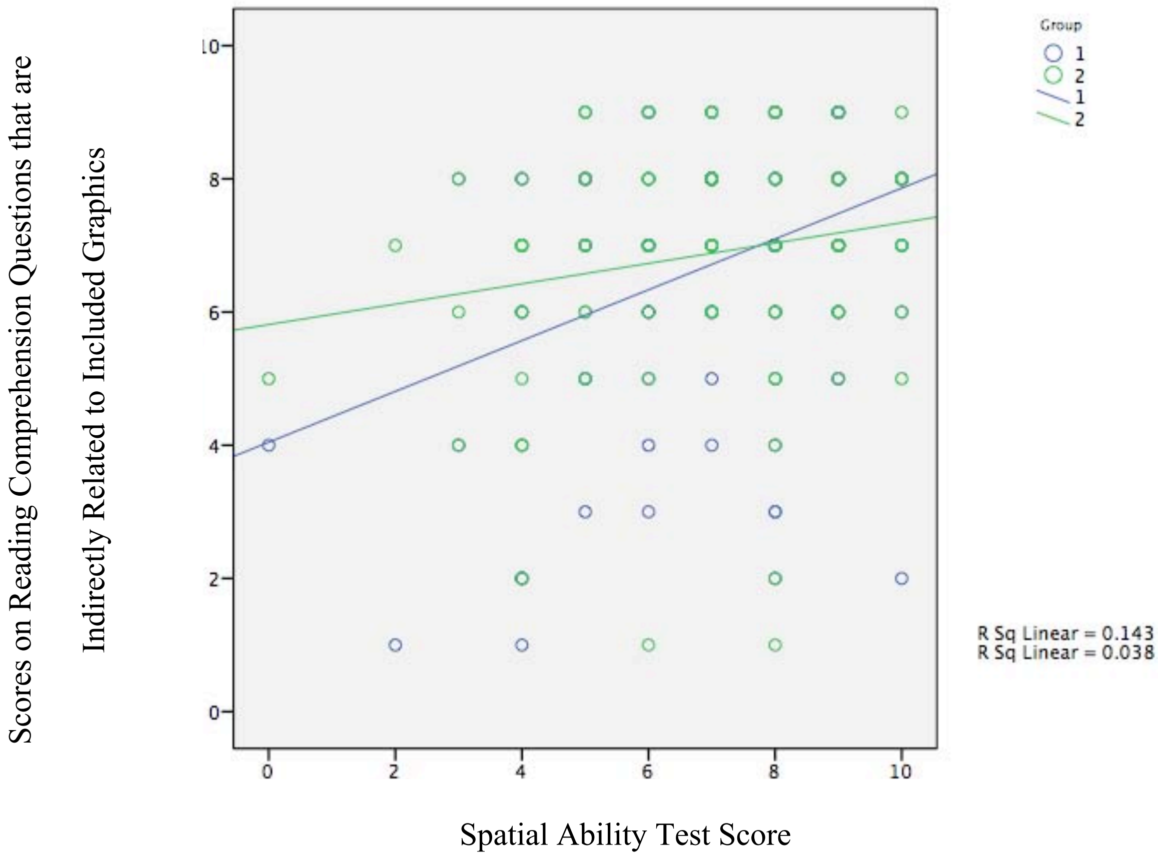
Do scores on reading comprehension questions that are indirectly related to included graphics differ between groups when controlling for spatial ability?

A one-way ANCOVA was planned. The grouping variable included the text only group and the text and graphics group. The dependent variable was the scores on reading comprehension questions that are indirectly related to included graphics and the covariate was spatial ability. The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, spatial ability, and the dependent variable, scores on reading comprehension questions that are indirectly related to included graphics, did differ significantly between groups, $F(1, 229) = 4.13$, $p = .043$, partial $\eta^2 = .018$ (Table 25). Since the test for homogeneity of slopes was significant – meaning the assumption of equal slopes is false – the Johnson-Neyman procedure was used to determine points on the spatial ability scale where the difference between groups became statistically significant. The results of the Johnson-Neyman procedure indicated that for individuals with a spatial ability score below 7.43 their reading comprehension score is lower, but for individuals with a spatial ability score above 8.04 their reading comprehension score is higher. For individuals whose spatial ability score was between 7.43 and 8.04 there is insufficient evidence to conclude that spatial ability was either helpful or harmful to their reading scores on indirect reading comprehension questions that are indirectly related to the included graphics (Figure 13).

Table 25

Test of Homogeneity of Slopes for Between-group Spatial Ability with the Dependent Variable, Scores for Reading Comprehension Questions that are Indirectly Related to Included Graphics

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	418.91	1	418.91	142.86	.000	.384
Group	13.47	1	13.47	4.59	.033	.020
Spatial Ability	66.22	1	66.22	22.58	.000	.090
Group * Spatial Ability	12.12	1	12.12	4.13	.043	.018
Error	671.49	229	2.93			
Total	11596.00	233				



(Group 1○ / - Text Only; Group 2 ○ / - Text and Graphics)

Figure 13. Scatter plot depicting the relationship between the covariate, spatial ability, and the dependent variable, scores on reading comprehension questions that are indirectly related to included graphics.

Do scores on reading comprehension questions that are indirectly related to included graphics differ between groups when controlling for cognitive load?

The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, cognitive load, and the dependent variable, scores on reading comprehension questions that are indirectly related to included graphics, did not differ significantly between groups, $F(1, 229) = 1.17$, $p = .280$, $\eta^2 = .005$ (Table 26). The results of the ANCOVA indicated that the inclusion or exclusion of graphics in an Internet-based reading environment do not significantly affect reading comprehension scores when controlling for cognitive load, $F(1, 230) = .25$, $p = .616$, $\eta^2 = .001$. There is insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in reading comprehension scores between students who read essays with text only and students who read essays with text and graphics for questions that are indirectly related to included graphics when controlling for cognitive load. The results of the ANCOVA were summarized in Table 27.

Summary of research question #2.

Overall, there was insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there was no difference in reading comprehension scores between students who read essays with text only and students who read essays with text and graphics for questions that are directly or indirectly related to included graphics when controlling for the covariates, prior knowledge, spatial ability, and cognitive load. Based on the five ANCOVA tests and the test for simple group main effects, the inclusion of graphics in online reading environments did not affect the outcome of reading comprehension tests.

Table 26

Test of Homogeneity of Slopes for Between-group Cognitive Load Self-reports with the Dependent Variable, Scores for Reading Comprehension Questions that are Indirectly Related to Included Graphics

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1697.68	1	1697.68	667.23	.000	.744
Group	2.06	1	2.06	.81	.369	.004
Cognitive Load	162.46	1	162.46	63.85	.000	.218
Group * Cognitive Load	2.98	1	2.98	1.17	.280	.005
Error	582.66	229	2.54			
Total	11596.00	233				

Table 27

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable, Scores for Reading Comprehension Questions that are Indirectly Related to Included Graphics, Controlling for the Covariate, Cognitive Load Self-reports

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1704.89	1	1704.89	669.57	.000	.744
Cognitive Load	159.51	1	159.51	62.64	.000	.214
Group	.64	1	.5	.25	.616	.001
Error	585.64	230	2.546			
Total	11596.00	233				

Research Question #3: Do multimedia reading environments affect readers' self-reported cognitive load?

Hypothesis #3: Undergraduate students who read in text only environments and undergraduate students who read in text and graphics environments will report equal amounts of cognitive load.

Analysis of covariance (ANCOVA) was conducted to determine if there were significant differences between the amount of cognitive load reported by participants in the text only group and participants in the text and graphics groups. The covariates, prior knowledge, spatial ability, and reading comprehension test scores, were included in the analysis. The text only group correlation coefficient for cognitive load and prior knowledge was $r = -.188$, the text only group correlation coefficient for cognitive load and spatial ability was $r = -.360$, and the text only group correlation coefficient for cognitive load and reading comprehension test scores was $r = -.517$. The correlation coefficients for cognitive load with the covariates spatial ability and reading comprehension test scores were significant at the $\alpha = .01$ level. The correlation coefficient for cognitive load and prior knowledge was significant at the $\alpha = .05$ level.

The text and graphics group correlation coefficient for cognitive load and prior knowledge was $r = -.177$, the text only group correlation coefficient for cognitive load and spatial ability was $r = -.232$, and the text only group correlation coefficient for cognitive load and reading comprehension test scores was $r = -.585$. The correlation coefficients for cognitive load and the covariate spatial ability was significant at the $\alpha = .05$ level, while the correlation coefficient for cognitive load and reading comprehension test scores was significant at the $\alpha =$ .01 level. The correlation coefficient for cognitive load and the covariate prior knowledge was not statistically significant and the $\alpha = .05$ level. The correlational analysis for research question three is summarized in Table 28.

Table 28

Pearson Correlations Between Cognitive Load and the Covariates, Prior Knowledge, Spatial Ability, and Reading Comprehension Test Score, Reported Within Groups

	Prior Knowledge		Spatial Ability		Reading Comprehension Test Score	
	r	p	r	p	r	p
Text Only Cognitive Load Score	-.188	.046	-.360	.000	-.517	.000
Text and Graphics Cognitive Load Score	-.177	.053	-.232	.011	-.585	.000

Do multimedia reading environments affect readers' self-reported cognitive load when controlling for prior knowledge?

A one-way analysis of covariance (ANCOVA) was conducted. The grouping variable included two levels: 1) the text only group and 2) the text and graphics group. The dependent variable was cognitive load and the covariate was prior knowledge. The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, prior knowledge, and the dependent variable, cognitive load, did not differ significantly between groups, $F(1, 229) = .03$, $p = .863$, $\eta^2 = .000$ (Table 29). Additionally, the ANCOVA was not statistically significant, $F(1, 230) = .14$, $p = .714$, $\eta^2 = .001$ (Table 30). Any indication of a significant relationship between the grouping variable and cognitive load self-report was absent, designated by the partial $\eta^2 = .001$. There was insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in cognitive load when controlling for prior knowledge.

Table 29

Test of Homogeneity of Slopes for Between-group Prior Knowledge with Cognitive Load as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	997.53	1	997.53	450.62	.000	.663
Group	.00	1	.00	.00	.975	.000
Prior Knowledge Test Score	17.39	1	17.39	7.86	.006	.033
Group * Prior Knowledge Test Score	.07	1	.07	.03	.863	.000
Error	506.94	229	2.21			
Total	6684.00	233				

Table 30

ANCOVA Summary Table Testing for Group Differences on the Dependent Variable Cognitive Load Controlling for the Covariate Prior Knowledge

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	997.47	1	997.47	452.50	.000	.663
Prior Knowledge Test Score	17.32	1	17.32	7.86	.005	.033
Group	.30	1	.30	.14	.714	.001
Error	507.00	230	2.20			
Total	6684.00	233				

Do multimedia reading environments affect readers' self-reported cognitive load when controlling for spatial ability?

A one-way analysis of covariance (ANCOVA) was conducted. The grouping variable included two levels: 1) the text only group and 2) the text and graphics group. The dependent variable was cognitive load and the covariate was spatial ability. The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, spatial ability, and the dependent variable, cognitive load, did not differ significantly, $F(1, 229) = .87, p = .351, \eta^2 = .004$ (Table 31). Additionally, the ANCOVA was not statistically significant, $F(1, 230) = .05, p = .827, \eta^2 = .000$ (Table 32). Any indication of a significant relationship between the grouping variable and cognitive load was absent, designated by the partial $\eta^2 = .000$. There is insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in cognitive load when controlling for spatial ability.

Table 31

Test of Homogeneity of Slopes for Between-group Spatial Ability with Cognitive Load as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	774.13	1	774.13	370.33	.000	.618
Group	1.92	1	1.92	.92	.339	.004
Spatial Ability	45.10	1	45.10	21.58	.000	.086
Group * Spatial Ability	1.83	1	1.83	.87	.351	.004
Error	478.70	229	2.09			
Total	6684.00	233				

Table 32

ANCOVA Summary Table Testing for Group Differences on Cognitive Load Controlling for the Covariate Spatial Ability

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	774.66	1	774.66	370.79	.000	.617
Spatial Ability	43.80	1	43.80	20.97	.000	.084
Group	.10	1	.10	.05	.827	.000
Error	480.53	230	2.09			
Total	6684.00	233				

Do multimedia reading environments affect readers' cognitive load when controlling for reading comprehension test scores?

A one-way analysis of covariance (ANCOVA) was conducted. The grouping variable included two levels: 1) the text only group and 2) the text and graphics group. The dependent variable was cognitive load and the covariate was reading comprehension test scores. The assumption of homogeneity-of-slopes was evaluated first. The results indicated that the relationship between the covariate, reading comprehension test scores, and the dependent variable, cognitive load, did not differ significantly, $F(1, 229) = 2.34$, $p = .128$, $\eta^2 = .010$ (Table 33). Additionally, the ANCOVA was not statistically significant, $F(1, 230) = .16$, $p = .69$, $\eta^2 = .001$ (Table 34). Any indication of a significant relationship between the grouping variable and cognitive load was absent, designated by the partial $\eta^2 = .001$. There is insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no difference in cognitive load when controlling for reading comprehension test scores.

Summary of research question #3.

Overall, there was insufficient evidence at the α=.05 level to reject the null hypothesis that there is no difference in cognitive load when controlling for the covariates, prior knowledge, spatial ability, and reading comprehension test scores. Based on the three ANCOVA tests, the inclusion of graphics in online reading environments did not affect the amount of cognitive load reported.

Table 33

Test of Homogeneity of Slopes for Between-group Reading Comprehension Scores with Cognitive Load as the Dependent Variable

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1075.77	1	1075.77	680.70	.000	.748
Group	3.95	1	3.95	2.50	.115	.011
Reading Comprehension Test Scores	160.99	1	160.99	101.87	.000	.308
Group * Reading Comprehension Test Scores	3.69	1	3.69	2.34	.128	.010
Error	361.91	229	1.58			
Total	6684.00	233				

Table 34

ANCOVA Summary Table Testing for Group Differences on Cognitive Load Controlling for Reading Comprehension Test Scores

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1072.13	1	1072.13	674.48	.000	.746
Reading Comprehension Test Scores	158.73	1	158.73	99.86	.000	.303
Group	.25	1	.25	.16	.690	.001
Error	365.60	230	1.59			
Total	6684.00	233				

Research Question #4: Does a reader's self-reported cognitive load change based on spatial ability?

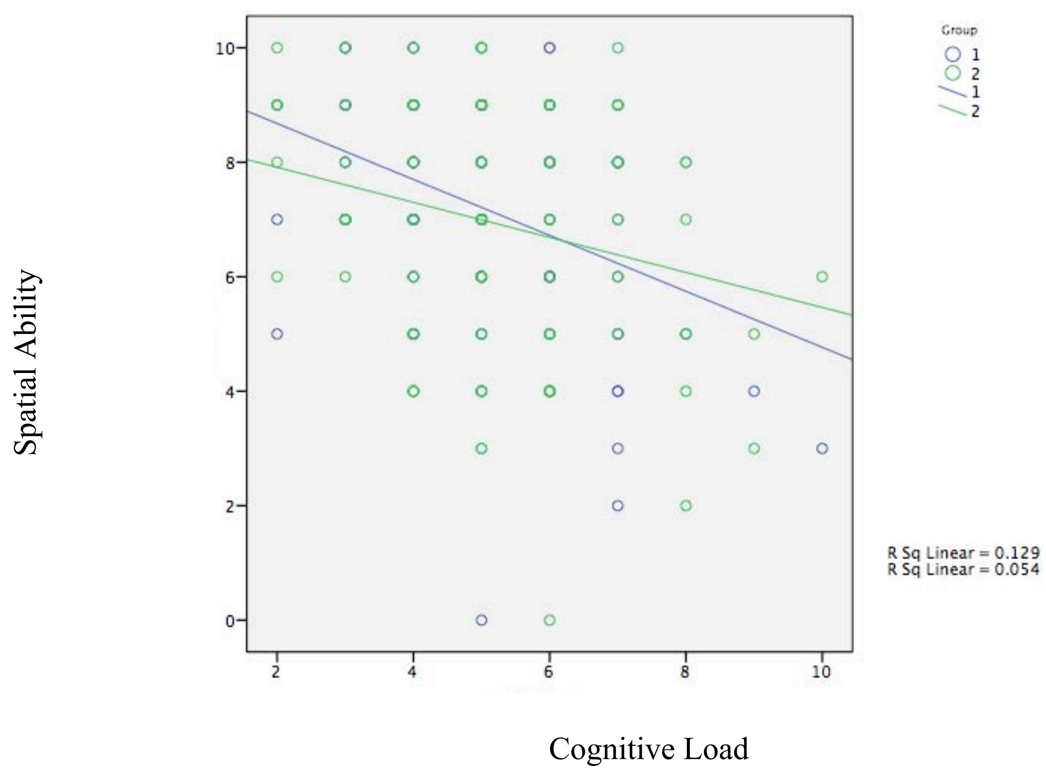
Hypothesis #4: There is no significant correlation between cognitive load and spatial ability for participants in the text only group and participants in the graphics and text group.

Pearson correlation coefficients were computed for cognitive load in relation to the spatial ability within groups. The results of the correlational analysis for the text only group indicated that the correlation coefficient between spatial ability and cognitive load was statistically significant at the $\alpha = .01$ level, $r = -.360$. There is sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there is no significant correlation between cognitive load and spatial ability for participants in the text only group.

The results of the correlational analysis for the text and graphics group indicated that the correlation coefficient between spatial ability and cognitive load was statistically significant at the $\alpha = .05$ level, r = -.232. There is sufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there no significant correlation between cognitive load and spatial ability for participants in the text and graphics group.

Summary of research question #4.

Overall, there was sufficient evidence to determine that readers' self-reported cognitive load changed based on spatial ability. Readers with higher spatial ability tended to experience lower cognitive load and readers with lower spatial ability tended to experience higher cognitive load regardless of the inclusion or exclusion of graphics. Figure 14 depicts the relationship between spatial ability and cognitive load for the text only and text and graphics groups.



(Group 1○ / - Text Only; Group 2 ○ / - Text and Graphics)

Figure 14. Scatter plot depicting significant relationship between cognitive load and spatial ability for text only participants (Group 1) and text and graphics participants (Group 2).

Research Question #5: Does a reader's reading comprehension test scores change based on the reader's prior knowledge?

Hypothesis #5: There is no significant correlation between prior knowledge and reading comprehension test scores for the text only group and the text and graphics group.

Pearson correlation coefficients were computed for prior knowledge in relation to reading comprehension test scores within groups. The results of the correlational analysis for the text only group indicated that the correlation between prior knowledge and reading comprehension test scores was statistically significant at the $\alpha = .01$ level, $r = .258$, $p = .006$. There is sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there is no significant correlation between prior knowledge and reading comprehension test scores was for participants in the text only group.

The results of the correlational analysis for the text and graphics group indicated that the correlation coefficient between prior knowledge and reading comprehension test scores was statistically significant at the $\alpha = .05$ level, $r = .189$, $p = .039$. There is sufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no significant correlation between prior knowledge and reading comprehension test scores for participants in the text and graphics group.

Summary of research question #5.

Overall, there was sufficient evidence to determine that a reader's reading comprehension test scores changed based on prior knowledge. Readers with higher prior knowledge tended to score higher on reading comprehension tests and readers with lower prior knowledge tended to score lower on reading comprehension tests regardless of the inclusion or exclusion of graphics. Figure 15 depicts the relationship between prior knowledge and reading comprehension test scores for the text only and text and graphics groups.

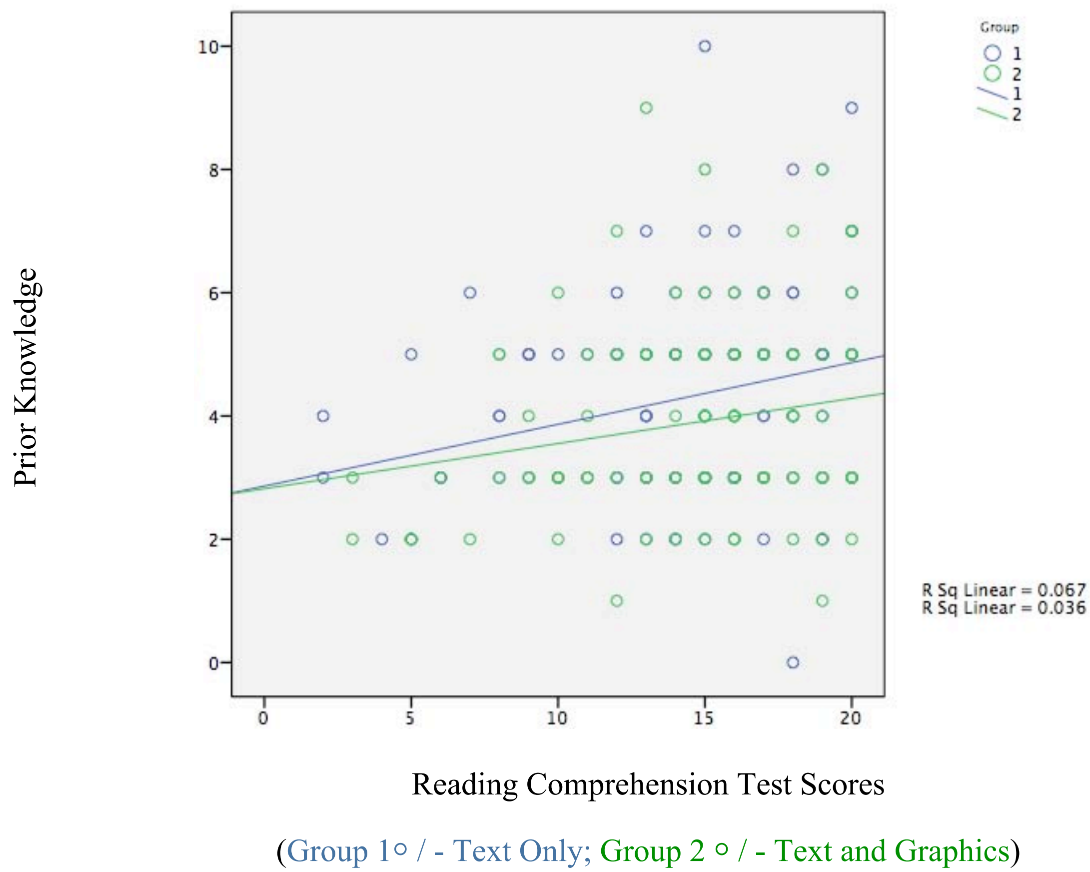


Figure 15. Scatter plot depicting significant relationship between reading comprehension test scores and prior knowledge for text only participants (Group 1) and for text and graphics participants (Group 2).

Research Question #6: Does a reader's cognitive load change based on the reader's prior knowledge?

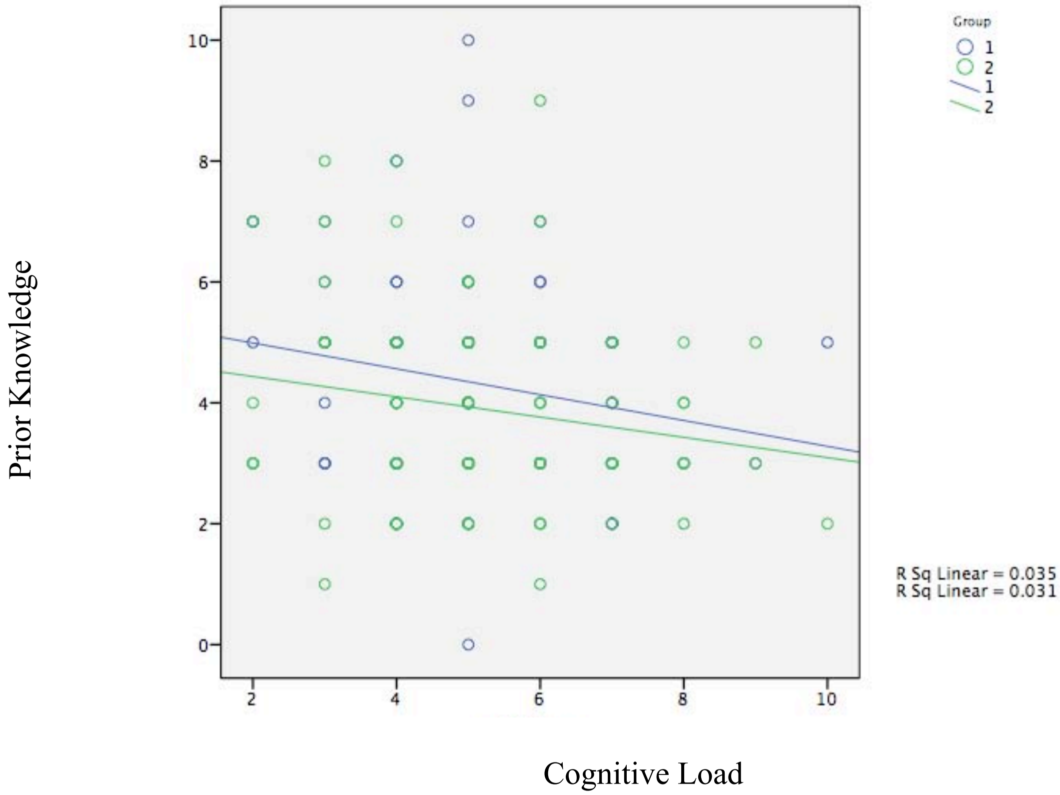
Hypothesis #6: There is no significant correlation between prior knowledge test scores and overall cognitive load reports for the text only group and for the text and graphics group.

Pearson correlation coefficients were computed for cognitive load in relation to prior knowledge within groups. The results of the correlational analysis for the text only group indicated that the correlation coefficient between cognitive load and prior knowledge was statistically significant at the $\alpha = .05$ level, $r = -.188$, $p = .046$. There was sufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no significant correlation between cognitive load and prior knowledge for participants in the text only group.

The results of the correlational analysis for the text and graphics group indicated that the correlation coefficient between cognitive load and prior knowledge was not statistically significant at the $\alpha = .05$ level, $r = -.177$, $p = .053$. There was insufficient evidence at the $\alpha = .05$ level to reject the null hypothesis that there is no significant correlation between cognitive load and prior knowledge for participants in the text and graphics group.

Summary of research question #6.

Overall, there was sufficient evidence to determine that readers' cognitive load changed based on prior knowledge for participants in the text only group but not for participants in the text and graphics group. Readers in the text only group with higher prior knowledge tended to report lower cognitive load scores and readers with lower prior knowledge tended to report higher cognitive load scores. Figure 16 depicts the relationship between cognitive load and prior knowledge for the text only and text and graphics groups.



(Group 1○ / - Text Only; Group 2 ○ / - Text and Graphics)

Figure 16. Scatter plot depicting the significant relationship between cognitive load and prior knowledge for text only participants (Group 1) and the insignificant relationship between cognitive load and prior knowledge for text and graphics participants (Group 2).

Research Question #7: Does a reader's reading comprehension scores change based on the reader's spatial ability?

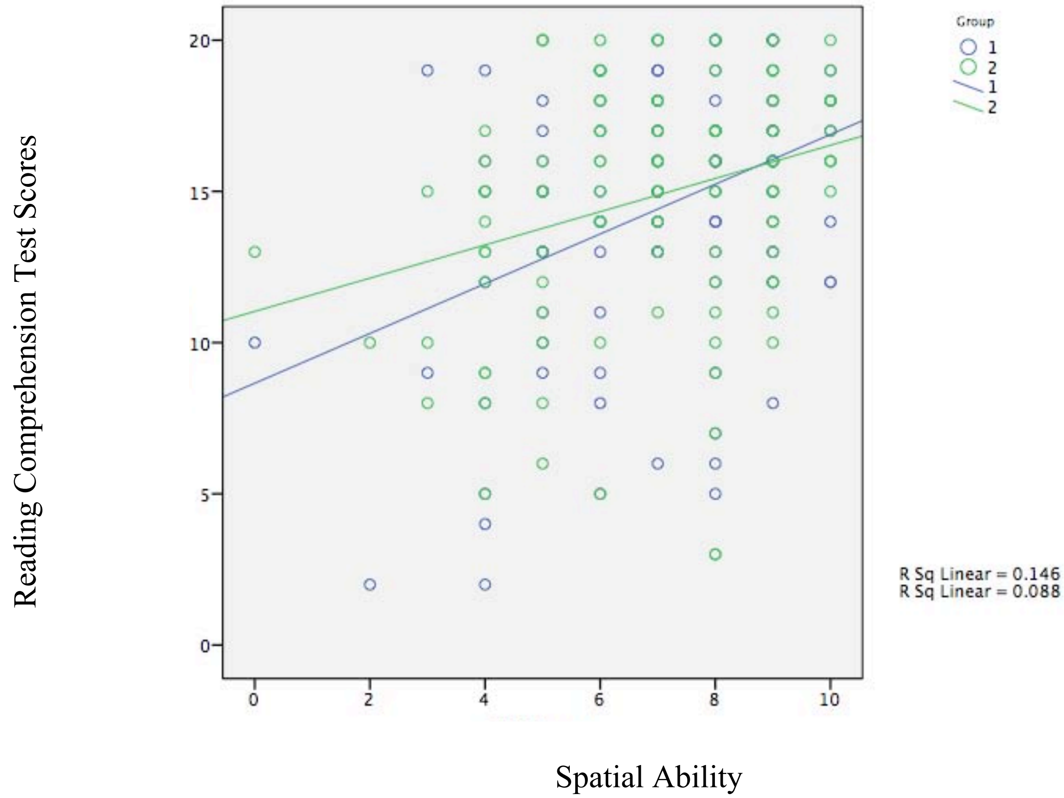
Hypothesis #7: There is no significant correlation between spatial ability and reading comprehension test scores for the text only group and the text and graphics group.

Pearson correlation coefficients were computed for spatial ability in relation to reading comprehension test scores within groups. The results of the correlational analysis for the text only group indicated that the correlation coefficient between spatial ability and reading comprehension test scores was statistically significant at the $\alpha = .01$ level, $r = .382$, $p = .000$. There was sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there was no significant correlation between spatial ability and reading comprehension test scores for participants in the text only group.

The results of the correlational analysis for the text and graphics group indicated that the correlation coefficient between spatial ability and reading comprehension test scores was statistically significant at the $\alpha = .01$ level, $r = .297$, $p = .001$. There was sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there was no significant correlation between spatial ability and reading comprehension test scores for participants in the text and graphics group.

Summary of research question #7.

Overall, there was sufficient evidence to determine that the readers' reading comprehension test scores changed based on their spatial ability. Readers with higher spatial ability tended to score higher on reading comprehension tests and readers with lower spatial ability tended to score lower on reading comprehension tests regardless of the inclusion or exclusion of graphics. Figure 17 depicts the relationship between cognitive load and prior knowledge for the text only and text and graphics groups.



(Group 1○ / - Text Only; Group 2 ○ / - Text and Graphics)

Figure 17. Scatter plot depicting the significant relationships between spatial ability and reading comprehension test scores for text only participants (Group 1) and text and graphics participants (Group 2).

Research Question #8: Does a reader's reading comprehension test scores change based on the reader's cognitive load?

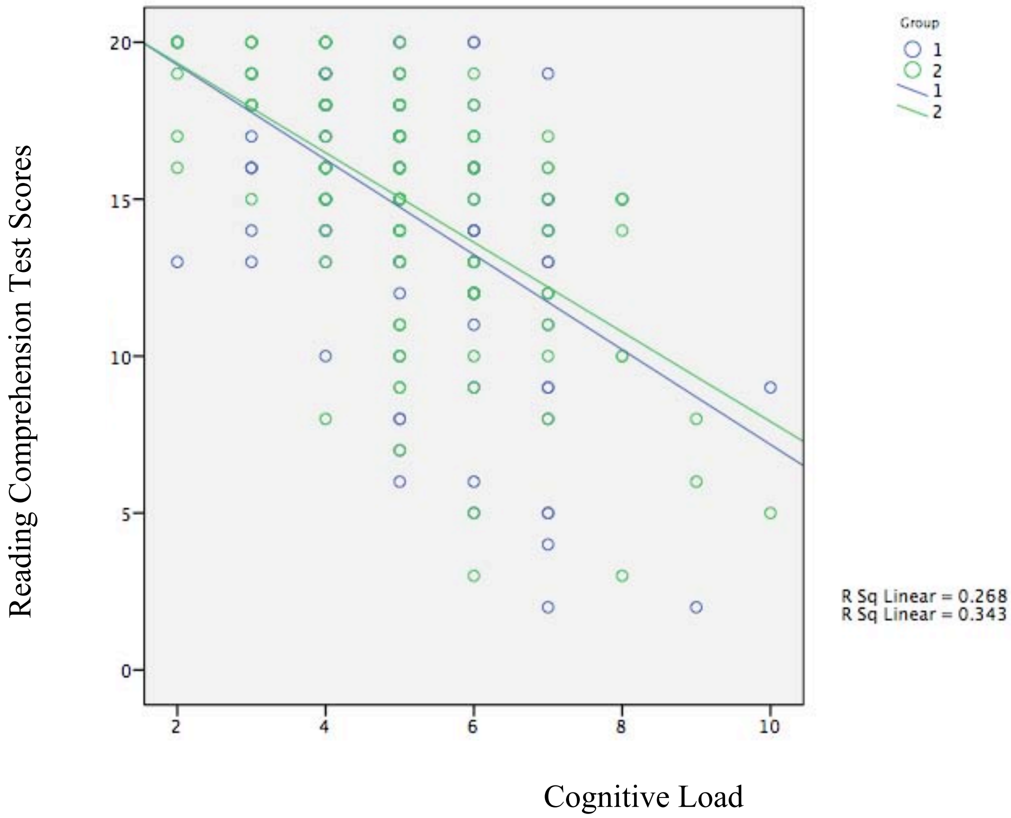
Research Question #8 Hypothesis: There is no significant correlation between reading comprehension test scores and cognitive load for the text only group and the text and graphics group.

Pearson correlation coefficients were computed for reading comprehension test scores in relation to cognitive load within groups. The results of the correlational analysis for the text only group indicated that the correlation coefficient between reading comprehension test scores and cognitive load were statistically significant at the $\alpha = .01$ level, $r = -.517$, $p = .000$. There was sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there was no significant correlation between reading comprehension test scores and cognitive load for participants in the text only group.

The results of the correlational analysis for the text and graphics group indicated that the correlation coefficient between reading comprehension test scores and cognitive load were statistically significant at the $\alpha = .01$ level, $r = -.585$, $p = .000$. There was sufficient evidence at the $\alpha = .01$ level to reject the null hypothesis that there was no significant correlation between reading comprehension test scores and cognitive load for participants in the text and graphics group.

Summary research question #8.

Overall, there was sufficient evidence to determine that reader's reading comprehension test scores changed based on their cognitive load. Readers with higher cognitive load tended to score lower on reading comprehension tests and readers with lower cognitive load tended to score higher on reading comprehension tests regardless of the inclusion or exclusion of graphics. Figure 18 depicts the relationship between reading comprehension test scores and cognitive load for the text only and text and graphics groups.



(Group 1○ / - Text Only; Group 2 ○ / - Text and Graphics)

Figure 18. Scatter plot depicting the significant relationships between reading comprehension test scores and cognitive load for text only participants (Group 1) and text and graphics participants (Group 2).

Summary of Results

Chapter four presented the statistical analysis results of the effects of Internet-based multimedia reading environments on reading comprehension, specifically focusing on the cognitive theory of multimedia learning's multimedia principle. The results of the analysis conducted for the eight research questions indicated the following:

1. The inclusion or exclusion of graphics in online reading environments did not affect the outcome of the reading comprehension test when controlling for the covariates, prior knowledge, spatial ability, or self-reported cognitive load.
2. The inclusion or exclusion of graphics in online reading environments did not affect the outcome of the reading comprehension questions that were directly or indirectly related to included graphics when controlling for the covariates, prior knowledge, spatial ability, and cognitive load.
3. The inclusion or exclusion of graphics in online reading environments did not affect the amount of cognitive load reported when controlling for the covariates, prior knowledge, spatial ability, and reading comprehension test scores.
4. Readers with higher spatial ability tended to experience lower cognitive load in online reading environments and readers with lower spatial ability tended to experience higher cognitive load in online reading environments regardless of the inclusion or exclusion of graphics.
5. Readers with higher prior knowledge tended to score higher on reading comprehension tests in online reading environments and readers with lower prior knowledge tended to score lower on reading comprehension tests in online reading environments regardless of the inclusion or exclusion of graphics.

6. Readers with higher prior knowledge tended to report lower cognitive load scores and readers with lower prior knowledge tended to report higher cognitive load scores in online reading environments the did not include graphics. Prior knowledge did not significantly relate to cognitive load for readers assigned to the online reading environment that included graphics.
7. Readers with higher spatial ability tended to score higher on reading comprehension tests and readers with lower spatial ability tended to score lower on reading comprehension tests regardless of the inclusion or exclusion of graphics in online reading environments.
8. Readers with higher cognitive load tended to score lower on reading comprehension tests and readers with lower cognitive load tended to score higher on reading comprehension tests regardless of the inclusion or exclusion of graphics in online reading environments.

The summary of this research study, discussion, and recommendations for future research are presented in Chapter 5.

CHAPTER 5

DISCUSSION

This study investigated the application of the cognitive theory of multimedia learning's multimedia principle on reading comprehension, specifically in Internet-based reading environments with undergraduate students. The multimedia principle posited, "People learn better from words and pictures than from words alone" (Mayer, 2009, p. 223). Does the multimedia principle apply to Internet-based reading environments?

The present study focused on two aspects of the multimedia principle. The first portion of the analysis investigated the reading comprehension differences between the treatment groups, text only and text and graphics. The results of the study indicated that the inclusion or exclusion of graphics had no impact on reading comprehension.

The second portion of the analysis investigated the impact that learner characteristics had on reading comprehension and cognitive load. The results of the study indicated that overall, higher prior knowledge and higher spatial ability were beneficial to reading comprehension and higher cognitive load was detrimental to reading comprehension.

The results of the statistical analysis conducted for the eight research questions resulted in eight conclusions. The first two are related to group differences and the remaining six are related to the learner characteristics. A discussion of this study's limitations, as well as each of the eight conclusions follows.

Limitations of the Study

Although the present study was conducted with the goal of high levels of rigor and the ability to generalize across populations, limitations existed that made this goal difficult. First, limiting the study's generalizability, targeted participants included volunteer undergraduate students from a large research university in the southeastern United States. By limiting the population represented in the study, generalizability to other populations is limited. Further studies, with target populations diverse in education, age, geographical regions, and culture should be conducted.

Second, several of the constructs investigated in the present study used correlational research design to evaluate the strength of the relationships between variables. Although several of the relationships were statistically significant, causes for the significant relationships were not determined or investigated. There was no evidence in the present study that would have indicated causal relationships between the variables, only that the relationships existed.

Third, the setting in which participants completed the research study may have introduced a great deal of variance into the statistical system. The present study asked participants to complete the data collection in their typical study environment – some participants may have completed the study in the library, the dorm room, the back of a classroom, or in front of the television. The increased variance introduced due to the setting in which the study was conducted may have affected the validity of the results of the statistical analysis. Validation studies that duplicate the conditions of this study should be conducted, as well as duplicate studies that are conducted in controlled settings.

Finally, the lack of statistical differences and minimal effect sizes when comparing groups in the present study may be indicative of a Type II error. Factors that may have contributed to a possible Type II error could include the violation of the ANCOVA assumption of normality, the fact that the essay did not need supporting graphics or that the supporting graphics used were not effective. Additionally, the variance introduced by the uncontrolled location of data collection may have also contributed to the possible Type II error.

Between-group Reading Comprehension Differences

The inclusion or exclusion of graphics in online reading environments did not affect the outcome of the reading comprehension test and the inclusion or exclusion of graphics in online reading environments did not affect the outcome of scores for reading comprehension questions that were directly or indirectly related to included graphics

The first portion of the present study focused on reading comprehension differences between readers who read in Internet-based reading environments that only included text and readers who read in Internet-based reading environments that included text and graphics. The differences were evaluated using the results of a multiple-choice reading comprehension test and the results of the analysis indicated non-significant differences between groups. The overall test of differences indicated that the inclusion or exclusion of graphics in online reading environments did not affect the outcome of the reading comprehension test.

Furthermore, when the reading comprehension questions were categorized based on whether they were directly or indirectly related to the included graphics, the results of the statistical analysis again indicated that the inclusion or exclusion of graphics in online reading environments did not affect the outcome of scores for reading comprehension questions that were directly or indirectly related to included graphics. The inclusion or exclusion of graphics in online reading environment did not affect the outcome of reading comprehension test scores; between group differences were not detected.

After evaluating the results of the statistical analysis one could have concluded that the cognitive theory of multimedia learning's multimedia principle did not apply to Internet-based reading environments. However, it was still necessary to look at differences between Mayer's (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) experiments and the present study to gain a more complete understanding of the differences in research study results. Specific experimental differences may have explained the differences in statistical results between Mayer's experiments and the results of the present study. Differences between the experiments included: instructional purpose and method of assessment, type of graphics included, and experimental setting. Further discussion of these differences follows.

Both Mayer's experiments and the present study under discussion were focused on learner understanding and gain of knowledge; however, significant overall differences existed. Mayer's (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) experiments included instructional content that was process-oriented, focusing on scientific systems. Participants were assessed using knowledge transfer tests, which evaluated systematic thinking and required participants to generate solutions to new problems. The present experiment included instructional presentations that were content-focused on the specific subject matter of color theory, and was assess using traditional reading comprehension methods. The reading comprehension test evaluated the reader's ability to glean facts from an essay presented immediately prior to answering the multiple-choice questions. It may have been possible that the cognitive theory of multimedia learning's multimedia principle is more applicable to learning outcomes and assessments focused on process-oriented, scientific instruction that are assessed through knowledge transfer rather than content-oriented instruction that is focused on gleaning facts from text that is assessed through multiple-choice questions.

Another significant difference between Mayer's (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) research and the present study was the difference in the types of graphics each researcher included in the text and graphics group. For decades, scholars and researchers have categorized instructional graphics in multiple ways based on their content, composition, medium, mode, and function. Mayer's (2009) proposed graphical categories included: decorative, representational, organizational, and explanative. Mayer's (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) experiments included explanative graphics depicting scientific systems such as a diagram of a pump or a braking system, while the present study included both representational graphics such as the American flag or a pink breast cancer ribbon, and organizational graphics such as the color wheel.

Mayer (2009) explained that pictorial and verbal representations were, "qualitatively different; by their natures, visual and verbal representations cannot be informationally equivalent" (p. 228). Following in the same vein of thought, different types of graphics may not be informationally equivalent either. The presence of unequivalent information may be indicated by the comparison of Mayer's research results to the results of the present study. It may be possible that the cognitive theory of multimedia learning's multimedia principle is more applicable to multimedia presentations that included explanative graphics than to multimedia presentations that included other types of graphics such as representational and organizational graphics. The included graphics could have been informationally unequal.

Finally, Mayer's experiments and the present experiment under discussion were conducted in different settings. Mayer's experiments have been conducted under great control in a laboratory environment. Distractions outside of the experiment were virtually eliminated. The present research study was conducted under much different conditions. Participants in the present study were requested to complete the experiment in their typical study environment. Some participants may have completed the study in the library, the dorm room, the back of a classroom, or in front of the television. The current experiment possibly exposed participants to a great deal of distraction while completing the data collection instruments, which may have introduced a great deal more variance into the statistical system and could have greatly affected the results of the analysis.

Continued research should be conducted to explore the differences between Mayer's research and the research currently under discussion. Mayer (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) has a plethora of research results supporting the application of the cognitive theory of multimedia learning to the study of scientific systems. Mayer (2009) explained, "multimedia works – that is, at least in the case of scientific explanations" (p. 239). The application of the cognitive theory of multimedia learning to explanations other than scientific failed to reach significance in the present study; however, to gain deeper understanding, further research is indicated.

Additionally, Mayer (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) has a vast amount of research results supporting the application of the cognitive theory of multimedia learning to content that includes explanative graphics. The present study, which investigated the application of the cognitive theory of multimedia learning using representational and organizational graphics, also failed to reach significance. Mayer (2009) suggested that the cognitive theory of multimedia learning's multimedia principle was vague – especially in understanding the types of graphics the principle may apply to. Again, further research is indicated to gain understanding of the types of graphics that the cognitive theory of multimedia learning's multimedia principle may apply to.

Furthermore, the results of the present study were derived from data collected in participants' "typical study environment." Mayer's (1989; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Moreno & Mayer, 2002) research that has consistently indicated significance for the cognitive theory of multimedia learning's multimedia principle has continually been conducted in strictly controlled, laboratory environments. Although the present study failed to reach significance, whether or not the cognitive theory of multimedia learning's multimedia principle is applicable to "typical study environments" is unknown. Differences between the research studies that support the cognitive theory of multimedia learning's multimedia principle and the present study such as the types of graphics included or the manner of assessment may have also contributed to the lack of statistical significance. Further research is indicated to gain greater understanding of the applicability of the cognitive theory of multimedia learning's multimedia principle within non-laboratory environments.

Learner Characteristics

Learner characteristics can affect the success of instruction. Prior knowledge, spatial ability, and cognitive load are learner characteristics that have been identified through empirical research to impact learning in multimedia environments. The second portion of the present study investigated the effect that individual learner characteristics had on the participants' reading comprehension test scores. Prior research studies focusing on learner characteristics have indicated an impact on the success of instruction. The learner characteristics addressed in the present study included: prior knowledge, spatial ability, and cognitive load. Overall, the results of the present study indicate that higher levels of prior knowledge and spatial ability are beneficial to the reader and higher levels of cognitive load are detrimental to the reader. The discussion of the effect that individual learner characteristics had on the participants' reading comprehension test scores is presented below.

Prior Knowledge

Readers with higher prior knowledge tended to score higher on reading comprehension tests in online reading environments and readers with lower prior knowledge tended to score lower on reading comprehension tests in online reading environments regardless of the inclusion or exclusion of graphics.

Prior knowledge, an individualized learner characteristic, can aid learners; however, it may also hinder learning by inhibiting the learner's ability to incorporate new knowledge into existing schema due to differences in content. According to Mayer (2009), Mayer and Sims (1994), and Mayer, Steinhoff, Bower, and Mars' (1995) research, multimedia effects are strongest for low-prior knowledge and high-spatial ability students. Based on the results of several empirical studies, Mayer (2009) indicated a boundary condition to the cognitive theory of multimedia learning's multimedia principle to describe the effect prior knowledge might have on learning. The boundary condition stated:

> The multimedia principle may apply more strongly to low-knowledge learners than to high-knowledge learners, presumably because low-knowledge learners need guidance in building connections between pictorial and verbal representations. (p. 223)

The boundary condition is termed the *expertise reversal effect* and was based on research conducted by Kalyuga, Ayres, Chandler, and Sweller (2003), among others.

Kalyuga (2005) explained the expertise reversal effect and how prior knowledge can affect multimedia learning by stating, "as levels of learner knowledge in a domain changed, relative effectiveness of different instructional formats reversed" (p. 327). Based on the research of Gyselinck and Tardieu (1999) and Mayer and Gallini (1990), Clark, Lyons, and Hoover (2004) developed a design guideline for learners with low prior knowledge, which stated that most low prior knowledge learners "benefit from the use of explanatory visual representations of content that are congruent with text because the visual can reduce [cognitive] load and provide a secondary route to forming mental models" (p. 196). However, Kalyuga, Chandler, and Sweller (2000) explained that once the learner "acquired sufficient knowledge to fully understand one source of information, additional sources that require integration and coordination will have deleterious effects unless he or she can ignore the secondary sources" (p. 128). According to Kalyuga, multimedia learning environments are most appropriate for low prior knowledge learners.

To address the multimedia principle's boundary condition in the present study, each participant was required to take a prior knowledge test. The results of the correlational analysis between prior knowledge and reading comprehension test scores indicated that there was a significant relationship. In fact, it was determined that readers with higher prior knowledge tended to score higher on the reading comprehension test and readers with lower prior knowledge tended to score lower on the reading comprehension test regardless of the inclusion or exclusion of graphics. The results of the present study did not support the expertise reversal effect and there appeared to be little impact on the reader from the included graphics.

The expertise reversal effect is a result of multimedia instruction where low prior knowledge learners assigned to the text and graphics group score higher on the reading comprehension test than the high prior knowledge learners. However, the results of the present study do not support the expertise reversal effect. Instead, the resulting relationship was directly opposite of the expertise reversal effect in the text and graphics group – the learners assigned to the text and graphics group with high prior knowledge tended to score higher on reading comprehension tests. The fact that the expertise reversal effect was not supported in the present study may indicate that the expertise reversal effect does not apply to reading comprehension. It may also be the result of differences between the present experiment and the prior experiments conducted by Kalyuga and his colleagues. These differences include the design of the multimedia treatment, the experimental design and setting, and the method of assessment.

Clark, Lyons, and Hoover (2004) developed a design guideline for high prior knowledge learners based on the expertise reversal effect research. The guideline stated that high prior knowledge learners, "benefit from either text or visuals alone rather than redundant representations of information" (p. 196). However, Kalyuga, Chandler, and Sweller (2000) further elaborated that once a learner mastered one source of information, additional sources of information that are included may be detrimental to the learner. In the present study, the format of the text and graphics essay, with the graphics placed to the right of the text, could have made the second set of information, the graphics, easy to ignore; however, the text and graphics included in Kalyuga et al.'s (2005) study were completely integrated and inseparable. The high prior knowledge learners that participated in the present study may have ignored the included graphics. Additional research is needed to determine if high prior knowledge readers ignore graphics included in multimedia reading environments – possibly using eye-tracking technology or follow-up questions to collect this information.

Another possible explanation for the difference in experimental results is the design of the experiment. Kalyuga's (2005) study was a longitudinal study in which participants were "gradually trained in relatively narrow domains from a novice to a relatively expert state" (p.

332), while the present study was conducted using a one-time data collection procedure; all parts of the data collection instrument were completed in one sitting. Kalyuga (2005) explained, "a full reversal effect was obtained only … in longitudinal studies" (p. 332). Furthermore, another possible explanation for the difference in experimental results also related to the design of the experiment is the experimental setting in which data was collected. Kalyuga's (2005) experiments that supported the expertise reversal effect were, "obtained only in strictly controlled experimental conditions" (p. 332), whereas the present study collected data from participants who completed the reading comprehension test in their typical study environment. The diversity in the experiment location may have impacted the results of the present study, limiting the ability to reproduce the expertise reversal effect. Additional research is needed to determine if the experimental design affects the reproduction of the expertise reversal effect.

Additionally, the method of assessment used by Kalyuga, Chandler, and Sweller's (2000) experiment that produced the expertise reversal effect was a 10 question multiple-choice test. Although the present study also employed a multiple-choice test, the intent of the questions included was different. The questions included by Kalyuga et al. (2000) asked participants to solve problems that required the application of knowledge gained through multimedia instruction. The questions included in the present study asked participants to recall facts that were gleaned from reading the essay. Additional research is indicated to determine if the expertise reversal effect is dependent on a particular method of assessment and to determine if the expertise reversal effect applies to reading comprehension tests.

Readers with higher prior knowledge tended to report lower cognitive load scores and readers with lower prior knowledge tended to report higher cognitive load scores in online reading environments that did not include graphics.

Clark, Lyons, and Hoover (2004) proposed a design guideline to support learners with low prior knowledge. The guideline stated that most low prior knowledge learners benefit from the addition of descriptive graphics to verbal content as long as they are congruent. The addition of the visual can offload cognitive load and enable learners to develop more schematic connections in long-term memory. However, for learners who have higher levels of prior knowledge, including graphics to verbal content may increase the learners' cognitive load. Kalyuga (2005) proposed that multimedia learning environments were most beneficial for low prior knowledge learners.

Based on Kalyuga's research, participants assigned to the text only group who have low prior knowledge should experience higher cognitive load than the participants who have high prior knowledge. Also, participants assigned to the text and graphics group who have high prior knowledge should experience higher cognitive load than the participants who have low prior knowledge. The results of the present study indicated that readers with low prior knowledge tended to experience higher cognitive load and readers with higher prior knowledge tended to experience lower cognitive load in the text only online reading environments. There was not a significant relationship between prior knowledge and cognitive load for readers assigned to the text and graphics reading environment. The present study was unsuccessful in fully duplicating Kalyuga's results. As predicted, prior knowledge was beneficial to readers in the text only reading environment; however, it was also beneficial to readers in the text and graphics reading environment as well.

By presenting a visual topic, color theory, without graphical representation of the visual content, low prior knowledge learners may have been unable to formulate a comprehensive understanding of the information, thereby increasing the difficulty and increasing their cognitive load. Furthermore, participants in the text only group with high prior knowledge may have been able to generate their own images to accompany the text. Kalyuga (2005) explained, " more knowledgeable learners already have and spontaneously use their sophisticated models" (p. 333). Learners with higher prior knowledge are able to support the construction of more complete schema by producing their own images based on their previous experiences. Learners with lower prior knowledge are unable to construct complete schema without the existence of the representative graphics.

Schnotz (2005) explained that comprehension based on multimedia reading environments "is highly dependent on what kind of information is presented and how it is presented" (p. 49); cognitive load may have the same dependency on information selection and presentation as well. Reading environments generate levels of intrinsic cognitive load through vocabulary, sentence, and content complexity. The inclusion of textual and graphical content may be deemed irrelevant to one reader, while relevant to another reader, depending on their prior knowledge. Too little information presented to a low prior knowledge learner may result in higher cognitive load, while, at the same time, too much information presented to a high prior knowledge learner may also result in higher cognitive load. Further research that investigates the sensitive relationship between prior knowledge, cognitive load, and reading comprehension is necessary to gain understanding that can be used to determine instructional design guidelines for multimedia reading and learning environments.

Spatial Ability

Readers with higher spatial ability tended to experience lower cognitive load in online reading environments and readers with lower spatial ability tended to experience

higher cognitive load in online reading environments regardless of the inclusion or exclusion of graphics.

According to Mayer (2005), spatial ability is necessary to learn from multimedia instruction that incorporates verbal and visual information. Mayer (2005) explained, "The ability to engage in spatial cognition is particularly important in multimedia learning… multimedia learners need to be able to form, hold, and use mental images" (p. 172). Mayer (2009), Mayer and Sims (1994), and Mayer, Steinhoff, Bower, and Mars (1995) explained that multimedia effects are strongest for low-prior knowledge and high-spatial ability learners. According to Mayer, participants assigned to the text and graphics group with higher spatial ability should have recorded a lower cognitive load than participants with lower spatial ability and participants assigned to the text only group with higher spatial ability should have recorded a higher cognitive load than participants with lower spatial ability. The results of the research, however, do not support these predicted results.

Through correlational analysis, the results of the present study indicated that readers with higher spatial ability tended to experience lower cognitive load in online reading environments and readers with lower spatial ability tended to experience higher cognitive load in online reading environments. These results were consistent across groups, regardless of the inclusion or exclusion of graphics. The inclusion or exclusion of graphics had no impact on the amount of cognitive load reported by participants. To explain the relationship between spatial ability and cognitive load, current research that focuses on the relationship between spatial ability and cognitive load should be reviewed; however, very little research explores this construct. We should also look more closely at the components included in the present study. Furthermore, the results of the present study may indicate that the spatial ability test may correlate with the results of an aptitude test.

The results of the correlational analysis for the text and graphics group partially duplicate the results of Mayer and Sims (1994) and Moreno and Mayer's (1999) research; readers in the text and graphics group who had higher spatial ability tended to experience lower cognitive load. However, the results for the text only group did not duplicate their results; readers in the text only group who had higher spatial ability also tended to experience lower cognitive load An explanation for the results of the present study may include the possibility that high spatial ability readers in the text only group were able to produce their own images as they read the text.

The subject of color theory is visual in nature. By presenting a visual topic without graphical representation of the visual contents, low spatial ability learners may have been unable to formulate a comprehensive understanding of the content, thereby increasing the difficulty and increasing their cognitive load. Furthermore, participants in the text only group with high spatial ability may have been able to generate their own images to accompany the text. After all, high spatial ability learners are able to "form, hold, and use mental images" (Mayer, 2005; p. 172). Another possible explanation may be that there is a significant positive relationship between spatial ability and reading comprehension achievement. Text is a visual component that is essential to the reading environment. Further research that investigates the relationship between reading comprehension and spatial ability is necessary to gain a clearer understanding.

Readers with higher spatial ability tended to score higher on reading comprehension tests and readers with lower spatial ability tended to score lower on reading comprehension tests regardless of the inclusion or exclusion of graphics in online reading environments.

Research conducted by Mayer and Sims (1994) and Moreno and Mayer (1999) indicated that high spatial ability learners outperformed low spatial ability learners in multimedia environments; however, only one group in the present study was exposed to a multimedia environment. The results of the present study indicated that, indeed, higher spatial ability readers tended to score higher than lower spatial ability readers; however, these results were not impacted by the inclusion or exclusion of graphics. In the present study, high spatial ability learners consistently outperformed low spatial ability learners. The inclusion or exclusion of graphics had no impact on the outcome; however, the higher levels of spatial ability tended to aid the reader.

To explain the relationship between spatial ability and reading comprehension test scores, we should look more closely at the present study, as well as, the prior research conducted by Mayer and his colleagues. Prior research conducted by Mayer and Sims (1994) focused on scientific systems – how breaking systems work and how the human respiratory system works. In both experiments participants were assessed using knowledge transfer tests. Their results indicated that in multimedia learning environments high spatial ability learners outperform low spatial ability learners on knowledge transfer tests. Furthermore, Moreno and Mayer (1999) exposed two groups of mathematics students to either single-representation lessons or multiple-representation lessons. The outcome of the math lessons was assessed using a measure of pre-test-to-post-test gain. Again, the results indicated that high spatial-ability students produced a significantly greater pre-test-to-post-test gain than did low spatial-ability students when exposed to the multiple-representation lesson.

Both Mayer and Sims (1994) and Moreno and Mayer's (1999) studies focused on scientific and mathematical processes. The effectiveness of the instruction was evaluated by asking participants to apply the knowledge gained, either through a knowledge transfer test or a mathematics test. The present study was more conventional, in that it was formatted as a traditional reading comprehension test, which was constructed of 20 reading comprehension questions that tested the reader's ability to glean facts from the essay. The differences in research results could be based on the differences between content and, possibly, assessment methods.

Furthermore, it may be possible that there is an existing relationship between spatial ability and reading comprehension. Spatial ability is defined as the ability to construct, manipulate, and maintain visual images in working memory; text is visual. Mayer (2005) explained, "Conventional instructional messages are heavily verbal, but multimedia messages are verbal and visual" (p. 172). However, reading environments are visual. It is possible that spatial ability is advantageous in reading environments due to the visual nature of text. Future research is necessary to explore the relationship between spatial ability and reading comprehension.

Cognitive Load

The inclusion or exclusion of graphics in online reading environments did not affect the amount of cognitive load reported when controlling for the covariates, prior knowledge, spatial ability, and reading comprehension test scores.

Cognitive load theory was first posited by Sweller (1988) to explain the impact that the limited capacity of working memory had on the learner. Cognitive load theory proposes that due to the limitations of working memory's capacity, demands on the information processing system may exceed the learner's capacity causing cognitive overload and missed stimulus. Although multimedia instruction oftentimes presents more information simultaneously, Mayer (2009) indicated, “When words and pictures are both presented, learners have an opportunity to construct verbal and visual mental models and to build connections between them” (p. 223), which was the fundamental implication of the cognitive theory of multimedia learning’s multimedia principle.

Furthermore, Sweller’s (1994) cognitive load theory explains that graphics should be used to present spatial structures, location, and detail, and words to present logical conditions, and abstract verbal concepts (Lohr, 2008; Ware, 2000). Organizational graphics can minimize learners’ cognitive load by externalizing complex information and off-loading extraneous processing (Tversky, Morrison, & Betrancourt, 2002). Including organizational graphics in multimedia instruction “helps learners understand the structure, sequence, and hierarchy of information and help[s] integrate that information” (Lohr, 2008, p. 18) into long-term memory. Organizational graphics aid the multimedia learner in developing a comprehensive understanding of the presented material by reducing learners’ cognitive load.

The results of the present study indicated that the inclusion or exclusion of graphics in online reading environments did not affect the amount of cognitive load reported; the results are also indicative of the complex relationships that exist between learner characteristics and academic performance. Based on the individualized characteristics of prior knowledge and spatial ability, what may seem instructionally difficult to one learner may be instructionally easy to another learner, resulting in different levels of cognitive load.

The random assignment of participants to treatments (text only and text and graphics) would have resulted in assigning some individuals to the text only group who were compatible learners with the content and design. However, other individuals who were assigned text only group may have perceived the text only environment as lacking in information necessary to fully understand the contents. The same holds true for individuals assigned to the text and graphics group. The contents and design may have been appropriate for some and inappropriate for others. Therefore, the outcome of equal amounts of cognitive load being reported for both treatment groups is expected. Cognitive load depends on the individual characteristics of the learner and how they interact with the instructional presentation.

Readers with higher cognitive load tended to score lower on reading comprehension tests and readers with lower cognitive load tended to score higher on reading comprehension tests regardless of the inclusion or exclusion of graphics in online reading environments.

Based on Sweller's (1988) explanation of cognitive load, we can conclude that increased levels of cognitive load can be detrimental to learning and reading comprehension. It was predicted that readers in the present study with higher cognitive load would score lower on reading comprehension tests and readers with lower cognitive load would score higher on reading comprehension tests. Detrimental cognitive load effects could increase extraneous cognitive load and reduce the necessary processing that occurs in germane cognitive load. The results of the analysis confirmed the prediction. Cognitive load was detrimental to readers' performance on the reading comprehension test.

Conclusion

The number of people engaging in Internet-based multimedia reading is increasing daily. Due to the advent of the Internet and the need to include the maximum amount of information on each web page, the typical reading environment is rapidly changing. The dominance of paper-based, text only presentations is rapidly declining, being replaced with the dominance of Internet-based multimedia presentations. Readers who are engaged in reading Internet-based text are required to recognize, interpret, and comprehend content within a multimedia environment and are increasingly engaged in Internet-based multimedia reading.

Does the Cognitive Theory of Multimedia Learning's multimedia principle apply to multimedia reading environments? The results of the present study indicated that the inclusion or exclusion of graphics had little or no affect on the results of the reading comprehension test. Overall, the results of the present study indicated that participants with higher prior knowledge and higher spatial ability reported lower cognitive load and participants who reported lower cognitive load scored higher on the reading comprehension test.

The investigated learner characteristics, prior knowledge, spatial ability, and cognitive load, had a greater perceived impact on reading comprehension than the inclusion or exclusion of graphics. The results of the present study indicated that participants with higher prior knowledge tended to score higher on the reading comprehension test. Additionally, participants with higher spatial ability tended to score higher on the reading comprehension test. However, participants who reported higher cognitive load tended to score lower on the reading comprehension test. The results of the present study indicated that learner characteristics did affect the outcome of reading comprehension tests. The relationships that exist between prior knowledge, spatial ability, and cognitive load within multimedia reading environments are extremely complex and sensitive to one another.

Additional research is indicated by the results of the present study. Future directions may include investigations into the types of graphics that the cognitive theory of multimedia learning's multimedia principle may apply to and the type of content that the cognitive theory of multimedia learning's multimedia principle may apply to. Furthermore, the relationships that exist between prior knowledge, spatial ability, and cognitive load should be investigated more thoroughly. Also, replication studies may be conducted in uncontrolled environments using Mayer's data collection instruments to gain an understating of the cognitive theory of multimedia learning outside of the laboratory. Through future research a more thorough understanding of these constructs can be developed.

As more readers engage in Internet-based multimedia reading, the more necessary research on multimedia reading comprehension becomes. Further research is necessary to understand how the complex processes of reading and comprehension are affected by Internet-based multimedia reading environments. Ultimately, the results of such research should be used to aid instructional designers in the development of multimedia environments.

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APPENDICES

Appendix A: Randomization Javascript

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">


<html xmlns="http://www.w3.org/1999/xhtml">

<head>

<meta http-equiv="Content-Type" content="text/html; charset=UTF-8" />

<title>Survey Start</title>

<script language="JavaScript">

<!-- Hide from old browsers  function picklink() { var linknumber = 2 ; var linktext =
"nolink.html" ; var randomnumber = Math.random() ; var linkselect = Math.round( (linknumber-
1) * randomnumber) + 1 ; if ( linkselect == 1)
{linktext="http://www.surveymonkey.com/s.aspx?sm=C_2fggCtYaqEJwApBg3IU8ig_3d_3d" }
if ( linkselect == 2)
{linktext="http://www.surveymonkey.com/s.aspx?sm=rPaX3x4_2foOAw4Pw8IokByA_3d_3d"
}                          return linktext; } // End of script -->

</SCRIPT>

</head>

<body>

<A HREF="" file://localhost/view-
source/http/::projects.coe.uga.edu:kal:onClick="this.href=picklink()" target="new"
toolbar="no">Please click here to begin the survey.</A>

</body>

</html>
```

Appendix B: Text Only Color Theory Essay

blue-green. Tertiary colors can be connected with two overlapping equilateral triangles.

Color schemes are used to explain different types of color combinations based on a color's placement on the traditional color wheel. Color schemes were developed to aid in the selection and the successful combination of colors. Basic color schemes may only include one or two colors. More complex color schemes, however, may include the combination of several colors.

The most basic color scheme is the monochromatic color scheme. Monochromatic color schemes include a single color along with tints and shades of that color. The only variation included in the monochromatic color scheme is the value of the chosen color. An example of a monochromatic color scheme would include red, pink (a tint of red), and maroon (a shade of red). Another example of a monochromatic color scheme would include pure blue, light blue, and dark blue.

Analogous color schemes include two or more colors that are next to each other on the color wheel. Examples of analogous color schemes include green, yellow-green, and yellow, or red, orange-red and orange. Analogous color schemes are often found in nature and can be pleasing to the eye. For example, think about the blend of green and yellow on a fall leaf.

Another basic color scheme is the complementary color scheme. Complimentary color schemes include two colors that are directly opposite of one another on the color wheel. Complimentary colors are connected with a straight line that reaches across the diameter of the color wheel's circle. Examples of complimentary color schemes include red and green or violet and orange.

A more complex color scheme includes the split complementary color scheme. The split complimentary color scheme includes a main color and the two colors that are next to its complementary color on the opposite side of the color wheel. Examples of split complimentary color schemes include violet, yellow-orange, and yellow-green, or green, red-orange, and red-violet.

Appendix C: Multimedia Color Theory Essay

Reading Passage

Carefully read the following essay.

Please DO NOT use your browser's back button

The traditional color wheel arranges colors into a circle (Figure 1). Each colors' position on the color wheel creates the foundation for color relationships or color schemes. Based on these color relationships and schemes, the traditional color wheel is used by artists and painters to guide the process of mixing paints, dyes, and inks. Additionally, the traditional color wheel is used in art and art education to teach color mixing.

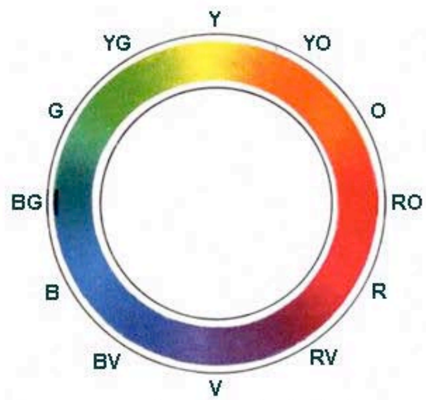

Figure 1. The traditional color wheel

The basic colors of the traditional color wheel are called primary colors and include red, yellow, and blue (Figure 2). It is impossible to make any of the primary colors by mixing together any other colors; however, the primary colors are used to make all other colors. Primary colors can be mixed in many ways to create every other color on the traditional color wheel. On the color wheel, primary colors are connected by an equilateral triangle and are equally spaced apart.


Figure 2. Primary colors


Figure 3. Tints

Black and white can also be added to all colors on the color wheel to change the colors' value. Adding white creates lighter values. Colors that are mixed with white are called tints (Figure 3). Adding black creates darker values. Colors that are mixed with black are called shades (Figure 4). Additionally, mixing together a color and its opposite color on the color wheel can reduce the intensity of a color. The result is called a tone (Figure 5).

Figure 4. Shades

Figure 5. Tones

In addition to primary colors, the traditional color wheel also includes secondary and tertiary colors. Mixing equal parts of two primary colors creates secondary colors including green, orange, and violet (Figure 6). Secondary colors are also connected by an equilateral triangle on the color wheel. Mixing equal parts of primary and secondary colors together creates tertiary colors (Figure 7). There are six tertiary colors including yellow-green, yellow-orange, red-orange, red-violet, blue-violet, and blue-green. Tertiary colors can be connected with two overlapping equilateral triangles.

Figure 6. Secondary colors

Figure 7. Tertiary colors

Color schemes are used to explain different types of color combinations based on a color's placement on the traditional color wheel. Color schemes were developed to aid in the selection and the successful combination of colors. Basic color schemes may only include one or two colors. More complex color schemes, however, may include the combination of several colors.

The most basic color scheme is the monochromatic color scheme (Figure 8). Monochromatic color schemes include a single color along with tints and shades of that color. The only variation included in the monochromatic color scheme is the value of the chosen color. An example of a monochromatic color scheme would include red, pink (a tint of red), and maroon (a shade of red). Another example of a monochromatic color scheme would include pure blue, light blue, and dark blue.

Figure 8. Monochromatic color scheme

Analogous color schemes (Figure 9) include two or more colors that are next to each other on the color wheel. Examples of analogous color schemes include green, yellow-green, and yellow, or red, orange-red and orange. Analogous color schemes are often found in nature and can be pleasing to the eye. For example, think about the blend of green and yellow on a fall leaf.

Figure 9. Analogous color scheme

Another basic color scheme is the complementary color scheme (Figure 10). Complementary color schemes include two colors that are directly opposite of one another on the color wheel. Complementary colors are connected with a straight line that reaches across the diameter of the color wheel's circle. Examples of complimentary color schemes include red and green or violet and orange.

Figure 10. Complimentary color scheme

A more complex color scheme includes the split complementary color scheme (Figure 11). The split complementary color scheme includes a main color and the two colors that are next to its complementary color on the opposite side of the color wheel. Examples of split complementary color schemes include violet, yellow-orange, and yellow-green, or green, red-orange, and red-violet.

Figure 11. Split complementary color scheme

Triadic color schemes include three equally spaced colors on the color wheel (Figure 12). Triadic color schemes are connected with an equilateral triangle. The three primary colors—red, yellow, and blue—are an example of a triadic color scheme. Additional triadic color schemes include orange, violet, and green (the secondary colors), and yellow-orange, red-violet, and blue-green.

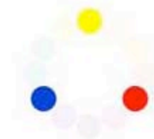

Figure 12. Triadic color scheme

Figure 13. Tetradic color scheme

The tetradic color scheme includes two sets of complementary colors that are equally spaced apart (Figure 13). For example, if red and green were your first set of complimentary colors, yellow-orange and blue-violet would need to be added to create a tetradic color scheme. Another example of the tetradic color scheme includes yellow, violet, red-orange and blue-green.

Figure 14. Example of symbolic color

Figure 15. Example of symbolic color

The colors within a color scheme can exist in their most pure form. Color schemes that are based on the purest colors can be very intense and may be difficult to work with. Complex color schemes such as the tetradic color scheme that include four complimentary colors can cause visual vibration and may be distracting to the viewer, especially when the colors are used at their peak intensity. By using the tint, shade, or tone of a color, the intensity and vibration may be reduced, resulting in a more pleasing experience for the viewer.

Color schemes are used in many professional situations. Artists and designers carefully consider color when designing logos, advertisements, web sites, book covers, magazine layouts, interiors, and even video games. Because consumers' perception of color and color schemes can impact their reaction to the product, colors and color schemes are carefully chosen by artists and designers to emote specific feelings from their viewers and customers.

Figure 16. Example of communicative color

Figure 17. Color wheel

Color alone can be symbolic, emotional, and can be used to communicate. Symbolic uses of color may include the colors on a national flag (Figure 14) or the pink colored ribbon (Figure 15) worn on a lapel. Color can also exude emotion. Just think about your school colors! Color can also be used to communicate. For example, the red light tells you to stop, the green cluster on a meteorologists' map tells you where the rain is falling (Figure 16), or the blue screen on a Windows PC tells you your computer has crashed.

Although on the surface color selection can seem fun and easy, color selection can be extremely complex and difficult. Additionally, the complexity of color selection is confounded by the emotional and aesthetic power of color. The color wheel helps to simplify this process by providing a foundation that can be used to define color relationships or color schemes (Figure 17). Color schemes provide logical structures for combining colors ranging from simple single color schemes to complex multi-color schemes. Color selection is not a simple process, but understanding the underlying foundation of color schemes can simplify the process.

Appendix D: Initial Instructor Email

Gmail by Google

Research Participation Request

Kristi Leonard <kal@uga.edu> **Date and Time**
To: XXX@uga.edu

Hi Dr. XXX,

My name is Kristi Leonard. I am a doctoral student in the Department of Educational Psychology and Instructional Technology majoring in Learning, Design, and Technology. My research area focuses on the Cognitive Theory of Multimedia Learning and its application to the design of online reading environments for reading comprehension. I am in the process of collecting dissertation data for my research this semester.

I am recruiting University of Georgia undergraduate students to volunteer to participate in my research study. I have contacted you because you are listed as the instructor of an undergraduate course being offered this semester, XXXX ####.

I would appreciate it if you would encourage your students to participate in this research study. For your convenience, I have prepared an email that you can copy and paste into a new email that could be sent to your current students. I am also very happy to come and talk to your students in person if you would prefer.

If you have any questions or concerns, please feel free to reply to this email or call me at (706) 340-7064.

_ _ _ _ _ _ _ _
Email for your students:

Dear students,

You have been invited to participate in a fellow UGA student's research study on reading comprehension. I encourage you to take 20 to 25 minutes to participate in this research study.

Click the following link to begin the survey and learn more about the research:

http://projects.coe.uga.edu/kal/

If you have any questions or concerns, please feel free to contact the researcher at kal@uga.edu or at (706) 340-7064.

Thank you,
Dr. XXXX

--
Kristi Leonard
Doctoral Student
Learning, Design, & Technology
Department of Educational Psychology and Instructional Technology
College of Education
University of Georgia
kal@uga.edu

Appendix E: Reminder Instructor Email

Kristi Leonard <kasleonard@gmail.com>

Fwd: Research Participation

Kristi Leonard <kal@uga.edu> **Sat, Jun 27, 2009 at 11:55 AM**
To: XXXXXXX@uga.edu

Hi Dr. XXXXXXXXXX,

I wanted to take a minute to follow up with you regarding my request for research participants (see below). Any help you can provide will be much appreciated.

Thanks for your time,
Kristi Leonard

---------- Forwarded message ----------
From: **Kristi Leonard** <kal@uga.edu>
Date: Sat, Jun 13, 2009 at 7:35 PM
Subject: Research Participation
To: XXXXXX@uga.edu

Dear Dr. **XXXXXXXXXX,**

My name is Kristi Leonard. I am a doctoral student in the Department of Educational Psychology and Instructional Technology majoring in Learning, Design, and Technology. My research area focuses on the Cognitive Theory of Multimedia Learning and its application to the design of online reading environments for reading comprehension. I am completing a pilot study this summer and hope to follow up with the final dissertation data collection this fall.

I am in the process of recruiting University of Georgia undergraduate students to volunteer to participate in my research study. I have contacted you because you are listed as the instructor of a large undergraduate course being offered this summer, XXXX ####.

I would appreciate it if you would encourage your students to participate in this research study. For your convenience, I have prepared an email that you can copy and paste into a new email that could be sent to your current summer session students.

If you have any questions or concerns, please feel free to reply to this email or call me at (706) 340-7064.

_ _ _ _ _ _ _ _
Email for your students:

Dear students,

You have been invited to participate in a fellow UGA student's research study on reading comprehension. I encourage you to take 15 to 20 minutes to participate in this research study.

Click the following link to begin the survey and learn more about the research:

http://projects.coe.uga.edu/kal/

If you have any questions or concerns, please feel free to contact the researcher at kal@uga.edu or at (706) 340-7064.

Thank you,
Dr. XXXXXX

--
Kristi Leonard
Doctoral Student
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--
Kristi Leonard
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Appendix F: Electronic Consent Form

Consent Form

Dear Participant,

You are invited to participate in a project conducted as part of the requirements for the Ph.D. in the Department of Educational Psychology and Instructional Technology at the University of Georgia. For this project I will be asking each participant to:

1. provide basic demographic information;
2. tell me what you know about the essay topic;
3. complete a cube comparison test;
4. read a short essay;
5. respond to reading comprehension questions; and then
6. tell me how easy or hard you thought the tasks were;

These steps should only take about 20 to 25 minutes of your time.

The research, which is part of my dissertation study, will be supervised by Dr. Robert Branch, Professor and Department Head, Department of Educational Psychology and Instructional Technology. Dr. Branch may be contacted by email at rbranch@uga.edu or by calling (706) 542-4110.

The purpose of this research project is to help researchers learn more about multimedia reading environments. The results of the research study may be published, but your name will not be used. In fact, the published results will be presented in summary form only. Your identity will not be associated with your responses in any published format.

For this project, I will collect the data from the participants and use the Statistical Package for the Social Sciences (SPSS) to analyze the data.

Please note that Internet communications are insecure and there is a limit to the confidentiality that can be guaranteed due to the technology itself. However, once we receive the completed surveys, we will store them in a locked cabinet in my office and destroy any contact information that we have by May 1, 2012. If you are not comfortable with the level of confidentiality provided by the Internet, please feel free to print out a copy of the survey, fill it out by hand, and mail it to me at the address given below, with no return address on the envelope.

Kristi Leonard
Department of Educational Psychology and Instructional Technology
University of Georgia
Room 630 Aderhold Hall
Athens, Georgia 30602

You are free to refuse to participate or withdraw your participation at any time should you become uncomfortable. If you have any questions or concerns, feel free to contact the researcher at (706) 340-7064 or kal@uga.edu. I hope you enjoy this opportunity to participate in an educational research project. Thank you very much for your time.

Sincerely,

Kristi A. Leonard
Doctoral Candidate
Learning, Design, and Technology

Robert Maribe Branch
Professor and Department Head
Educational Psychology and Instructional Technology

1. Please select the appropriate choice below regarding your participation in this study:

◯ I would like to participate in this research study.

◯ I choose NOT to participate in this research study.

Additional questions or problems regarding your rights as a research participant should be addressed to:

The Chairperson
Institutional Review Board
University of Georgia
612 Boyd Graduate Studies Research Center
Athens, Georgia 30602-7411
Telephone (706) 542-3199
E-Mail Address IRB@uga.edu.

Appendix G: Demographic Data Collection

Demographic Data

Please provide responses to the demographic information questions below. The information will only be used to describe the volunteers that participanted in the study. Your specific information will NOT be reported.

Please DO NOT use your browser's back button.

1. What is your age?

2. What is your gender?

- Female
- Male

Appendix H: Prior Knowledge Test

Prior Knowledge

Let's see what you already know about color theory. Take your time and answer the following questions to the best of your knowledge.

Please DO NOT use your browser's back button

1. The primary colors on a traditional color wheel include:
(provide as many answers as you can think of up to 3)

a.
b.
c.

2. A color's value can be changed by adding:
(provide as many answers as you can think of up to 2)

a.
b.

3. Common color schemes include:
(provide as many answers as you can think of up to 5)

a.
b.
c.
d.
e.

Appendix I: ETS Permission for Use of Spatial Ability Test

Gmail by Google

Kristi Leonard <kasleonard@gmail.com>

FW: KIT Agreement

Betancourt, Juana <jbetancourt@ets.org> **Thu, Jul 2, 2009 at 1:07 PM**
To: Kristi Leonard <kal@uga.edu>

Hi Kristi,

Received your signed agreement today. Thanks. Good luck on your research.

Have a happy and safe 4th!
Juana

From: Betancourt, Juana
Sent: Friday, June 26, 2009 2:47 PM
To: 'Kristi Leonard'
Subject: RE: FW: KIT Agreement

[Quoted text hidden]

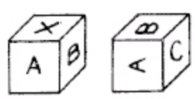
Appendix J: Cube Comparison Instructions and Sample Problems

Cube Comparison Test

This portion of the test is called the cube comparison test. I think it is fun. The directions and a few practice problems are below.

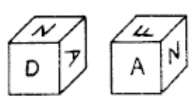
Please DO NOT use your browser's back button.

Wooden blocks that children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.



SAME

The pair above is the same and would be marked "Same" because they could be drawings of the same cube. That is, if A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.



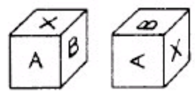
DIFFERENT

The second pair is shown as different, in which case you would mark the different box, because they must be drawings of different cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the right hand member of the pair. Thus, the drawings must be of different cubes.

<u>NOTE:</u> No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, <u>any</u> letter, number or symbol can be on the hidden faces of a cube.

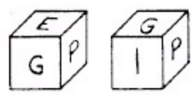
Use the next three exercises to practice the Cube Comparison Test.

1. Please decide if the pairs of cubes could be the same or if they are different and mark your choice below the image. Remember: No letters, numbers, or symbols appear on more than one face of a given cube.



- [ ] Same
- [ ] Different

2.



- [ ] Same
- [ ] Different

When you are ready to complete the Cube Comparison Test, click on the **Next** butt

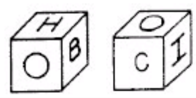
Appendix K: Cube Comparison Test

Cube Comparison Test

Now that you have had a chance to practice the cube comparison test, take your time and complete the following questions. Please decide if the pairs of cubes could be the same or if they are different and mark your choice below the image. Remember: No letters, numbers, or symbols appear on more than one face of a given cube.

Please DO NOT use your browser's back button.

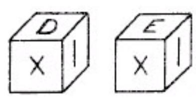
1.



Same ☐

Different ☐

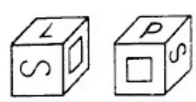
2.



Same ☐

Different ☐

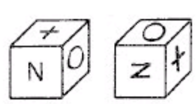
3.



Same ☐

Different ☐

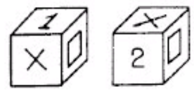
4.



Same ☐

Different ☐

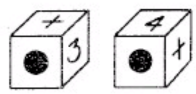
5.



Same ☐

Different ☐

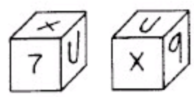
6.



Same ☐

Different ☐

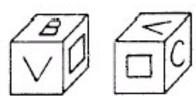
7.



Same ☐

Different ☐

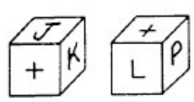
8.



Same ☐

Different ☐

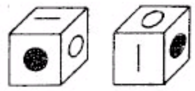
9.



Same ☐

Different ☐

10.



Same ☐

Different ☐

Appendix L: Reading Comprehension Test

Reading Comprehension Questions

The following reading comprehension questions are based on the essay that you just completed reading. Please take your time and answer the questions to the best of your knowledge.

Please DO NOT use your browser's back button

1. Based on color relationships and schemes, the traditional color wheel is used by artists and painters to guide the process of __________ paints, dyes, and inks.

- ◯ gradating
- ◯ mixing
- ◯ juxtaposing
- ◯ identifying
- ◯ exploring

2. The basic colors of the traditional color wheel are called ________ colors.

- ◯ foundation
- ◯ secondary
- ◯ initial
- ◯ tertiary
- ◯ primary

3. Primary colors can be mixed in many ways to create ____________ on the traditional color wheel.

- ◯ all but one color
- ◯ two colors
- ◯ one of the colors
- ◯ three colors
- ◯ every other color

4. On the traditional color wheel, primary colors are connected by a/an _______________ triangle.

- ◯ isosceles
- ◯ equilateral
- ◯ acute
- ◯ obtuse
- ◯ right

5. Colors that are mixed with white are called _________.

- ◯ tints
- ◯ shadows
- ◯ shades
- ◯ blends
- ◯ tones

6. Colors that are mixed with black are called _________.

- ◯ shadows
- ◯ blends
- ◯ tints
- ◯ tones
- ◯ shades

7. Mixing equal parts of two primary colors creates a ______________________ color.

- ◯ secondary
- ◯ primary
- ◯ tertiary
- ◯ triad
- ◯ tetrad

8. Secondary colors are connected by a/an _______________ on the color wheel.

- equilateral triangle
- rectangle
- obtuse triangle
- right triangle
- square

9. Mixing equal parts of primary and secondary colors together creates a _______________ color.

- secondary
- tetradic
- triadic
- tertiary
- primary

10. Tertiary colors can be connected with two _________________ triangles.

- acute
- equilateral
- right
- obtuse
- isosceles

11. Color schemes are used to explain different types of color combinations based on a color's __________ on the traditional color wheel.

- placement
- rank
- partner
- subordinate
- neighbor

12. ________________ is one of the most basic color schemes.

- ◯ Tetrad
- ◯ Double complementary
- ◯ Monochromatic
- ◯ Triadic
- ◯ Split Complementary

13. Monochromatic color schemes include a single color along with _________________.

- ◯ neighbors
- ◯ the primary colors
- ◯ tints and shades
- ◯ the secondary colors
- ◯ complements

14. Analogous color schemes include two or more colors that are ___________ on the color wheel.

- ◯ not neighbors
- ◯ opposite
- ◯ split apart
- ◯ complimentary
- ◯ adjacent

15. Complementary color schemes include two colors that are ______________ on the color wheel.

- ◯ adjacent
- ◯ subordinate
- ◯ dominant
- ◯ neighbors
- ◯ opposite

16. The split complementary color scheme includes a main color and _______________.

- ◯ its neighbors
- ◯ tertiary colors
- ◯ complementary color
- ◯ two colors adjacent to its complementary color
- ◯ primary colors

17. ____________________ are an example of a triadic color scheme

- ◯ Yellow, orange, green
- ◯ Green, yellow-green, yellow
- ◯ Blue, violet, yellow
- ◯ Red, yellow, blue
- ◯ Red, green, blue

18. ________________ are carefully chosen by artists and designers to emote specific feelings from their viewers and customers.

- ◯ Primary colors
- ◯ Secondary colors
- ◯ Color schemes
- ◯ Tones
- ◯ Shades

19. _____________ uses of color may include the colors on a national flag or the pink colored ribbon worn on a lapel.

- ◯ Arbitrary
- ◯ Symbolic
- ◯ Questionable
- ◯ Negative
- ◯ Subtle

20. A ____________ use of color may include the red light that tells you to stop.

- ◯ communicative
- ◯ awkward
- ◯ subordinate
- ◯ emotional
- ◯ uninformed

Appendix M: Cognitive Load Self-report Questions

Cognitive Load Questions

Did you think that reading the essay and answering the questions was easy or hard? Let me know. Please answer the following questions about the difficulty of reading the essay and answering the reading comprehension questions as accurately as possible.

Please DO NOT use your browser's back button.

---

1. How difficult was it to read the color theory article?

- ◯ Very High Difficulty
- ◯ High Difficulty
- ◯ Moderate Difficulty
- ◯ Low Difficulty
- ◯ Very Low Difficulty

2. How difficult was it to answer the reading comprehension questions?

- ◯ Very High Difficulty
- ◯ High Difficulty
- ◯ Moderate Difficulty
- ◯ Low Difficulty
- ◯ Very Low Difficulty

Appendix N: Student Volunteer Recruitment Flyer

Volunteers Needed!

Participate in a Fellow UGA Student's Research Study

Go To: http://projects.coe.uga.edu/kal/

And Complete the Reading Comprehension Test

It will only take 15 to 20 minutes of your time!

This opportunity is only available until Date. You may be eligible for a **$10 gift certificate!**

Contact kal@uga.edu or (706) 340-7064 if you have any questions.

Volunteers Needed!

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Contact kal@uga.edu or (706) 340-7064 if you have any questions.

Appendix O: Participant Thank you

Thank you!

Thank you so much for your time.

If you have any questions or concerns at this time, please feel free to contact Kristi Leonard at (706) 340-7064 or kal@uga.edu.

Additional questions or problems regarding your rights as a research participant should be addressed to:
The Chairperson
Institutional Review Board
University of Georgia
612 Boyd Graduate Studies Research Center
Athens, Georgia 30602-7411
Telephone (706) 542-3199
E-Mail Address IRB@uga.edu.

Appendix P: IRB Approval

Gmail by Google

Kristi Leonard <kasleonard@gmail.com>

IRB Approval- Amendment- Branch

Larie Sylte <lsylte@uga.edu> **Mon, Oct 19, 2009 at 4:45 PM**
To: "rbranch@uga.edu" <rbranch@uga.edu>
Cc: "kal@uga.edu" <kal@uga.edu>

PROJECT NUMBER: 2009-10887-1
TITLE OF STUDY: Cognitive Theory of Multimedia Learning for the Design of Online Multimedia Reading Environment
PRINCIPAL INVESTIGATOR: Dr. Robert Maribe Branch

Dear Dr. Branch,

Please be informed that the University of Georgia Institutional Review Board (IRB) has reviewed and approved your request for modifications to the above-titled human subjects proposal. It was determined that the amendment request continues to meet the criteria for exempt (administrative) review procedures.

You may now begin to implement the amendment. Your approval packet will be sent via campus mail.

Please be reminded that any changes to this research protocol must receive prior review and approval from the IRB. Any unanticipated problems must be reported to the IRB immediately. The principal investigator is also responsible for maintaining all applicable protocol records (regardless of media type) for at least three (3) years after completion of the study (i.e., copy of approved protocol, raw data, amendments, correspondence, and other pertinent documents). You are requested to notify the Human Subjects Office if your study is completed or terminated.

Good luck with your study, and please feel free to contact us if you have any questions. Please use the IRB number and title in all communications regarding this study.

Regards,

LaRie Sylte, M.H.A, M.A., CIP
Human Subjects Office
University of Georgia
www.ovpr.uga.edu/hso/