5-1-2013

Effective Use of Multimedia Presentations to Maximize Learning Within High School Classrooms

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EFFECTIVE USE OF MULTIMEDIA PRESENTATIONS TO MAXIMIZE LEARNING WITHIN HIGH SCHOOL SCIENCE CLASSROOMS

By

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A dissertation submitted in partial fulfillment of the requirements for the

Doctor of Philosophy in Learning and Technology

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University of Nevada, Las Vegas
May 2013
THE GRADUATE COLLEGE

We recommend the dissertation prepared under our supervision by

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entitled

Effective Use of Multimedia Presentations to Maximize Learning within High School Science Classrooms

be accepted in partial fulfillment of the requirements for the degree of

**Doctor of Philosophy in Learning and Technology**
Department of Educational Psychology and Higher Education

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ABSTRACT

Effective use of Multimedia Presentations to Maximize Learning Within High School Science Classrooms

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This research used an evidenced-based experimental 2 x 2 factorial design General Linear Model with Repeated Measures Analysis of Covariance (RMANCOVA). For this analysis, time served as the within-subjects factor while treatment group (i.e., static and signaling, dynamic and signaling, static without signaling, and dynamic without signaling) served as the between-subject independent variable. Three dependent variables were used to assess learner outcomes: (a) a 14 multiple-choice pre and post-test to measure knowledge retention, (b) a pre and post-test concept map to measure synthesis and structure of knowledge, and (c) four questions based on a Likert scale asking students to rank the cognitive difficulty of understanding four aspects of the animation they engaged in. A mental rotations test was used in the pretest conditions to establish a control and used as a covariate.

The treatment contained a four minute and 53 second animation that served as an introductory multimedia presentation explaining the gravitational effects of the moon and sun on the earth. These interactions occur at predictable times and are responsible for creating the tidal effects experienced on Earth. There were 99 volunteer high school
participants enrolled in science classes randomly assigned to one of four treatment conditions. The research was conducted to determine how motion and the principle of signaling, established in The Cognitive Theory of Multimedia Learning affected precollege learners. The experiment controlled for modality, segmenting, temporal contiguity, redundancy, and navigational control. Results of the RM ANCOVA indicated statistical significance for the within subjects effect: over time for all participants, with time and knowledge retention measured from the multiple-choice results, and in the category quality of concepts represented in the concept map analysis. However, there were no significant differences in the between groups analysis for knowledge retention based on the multiple-choice assessment, or among groups over time in the concept map variables number of concepts, levels, and quality of concepts. Additionally, when measuring cognitive difficulty when learning from the animations, no significant differences were measured.
ACKNOWLEDGEMENTS

I would like to thank Dr. Schrader, my advisor and chair for all the guidance, support, and time he provided for me. His patience and depth of knowledge was a true asset to this project. I also need to thank Dr. Bailey, Dr. Crippen, and Dr. Boone for also having patience and making the time for me when I really needed it. Additionally, I need to thank Dr. Nussbaum because it was his classes on cognitive science that kept me from dropping out of the program. Your insight, knowledge, and passion for the science of cognition really changed my future. Dr. Nussbaum, thank you.

I need to thank Debbie Brockett for encouraging me to practice so many of the strategies and techniques I learned at UNLV in my classroom lessons. Your support and encouragement empowered me to incorporate the large amount of material I learned as a PhD student with what I learned as a classroom teacher. My students and I appreciate that. I also need to thank all the teachers and friends I worked with over the last 20 years that helped shape and direct the path I followed. Thank you Bob Kessler, Rob Mattson, Sean Purtill, Lisa Collette, Ed Joyce, Jeff Stauty, Mike Halliday, and an extra special thank you too Gordy Wells. Gordy you helped me stay focused during a time in my life when I could have easily gone down a very different path. Your wisdom to see past the distractions and focus on the goals came at a critical time, thank you for being there.

I can’t imagine finishing this without the support of my family. Jamie, Keith, Kyle and Deanna I just need to say thank you for supporting my dreams for not just this PhD, but through all my adventures. I would never trade being the baby of our family for any other position. And to my parents, Burleigh and Arlene it goes without saying I would never have reached my goals with out your consistent support.
Finally, my wife Kristine is the one person who has been with me through every semester, every course, and every bump in the road. While you didn’t write the dissertation or conduct the research, without you none of this would ever have happened and I would never have fulfilled this goal. Finding you will always be the greatest thing to ever happen to me. Thank you for always being there and never giving up. I love you Kristine.
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CHAPTER 1

INTRODUCTION

The research reported here used high school aged participants in a classroom setting to determine the educational benefits of using motion and applying the principle of signaling from the Cognitive Theory of Multimedia Learning (CTML) into multimedia-based instruction. As a result, findings will address issues of generalizability and validity that currently face multimedia research. This research examined instructional multimedia design principles with a pre-college participant population that often possesses lower prior knowledge and evolving learning strategies instead of a college participant population used to establish many of the CTML principles. Specifically, this research investigated the effects of using animations containing motion or static images while incorporating or eliminating the CTML principle of signaling. Both motion and signaling are believed to influence the cognitive demands in working memory and thus served as the independent variables for this research. The treatment conditions for this research consisted of animations that reflect the presence or absence of the independent variables. Participants were randomly assigned to one of four conditions: dynamic with signaling, dynamic without signaling, static with signaling, static without signaling. A between subjects design was used with the following two groups: motion animations with or without signaling, and static image animations with or without signaling.

Motion in multimedia presentations represents some contextual change from one frame to the next. The images may change in size, shape, color, texture, the movement of entire entities, or the appearance or disappearance of an entity (Lowe, 2004). Animations may be defined as a sequence of rapidly changing computer screen or television images.
implying movement to the user (Höffler & Leutner, 2007). A static animation contains a visual image that does not change from one frame to the next but may show changes over the length of the presentation, whereas an animation with motion has some element or movement change from one frame to the next. Research has yet to definitively determine if motion or static animations are more beneficial when designing multimedia presentations (Hasler, Kersten & Sweller, 2007; Höffler, Prechtl & Nerdel, 2010; Münzer, Seufert & Brünken, 2009; Tversky, Morrison & Betrancourt, 2002).

Signaling cues direct the learners’ attention to important information (Mautone & Mayer, 2001) and can be accomplished in a multitude of ways including: underlining key sentences in a passage, highlighting key words in a section of text, diagram, or graph, blocking, or graying out visual information in an animation. Visual cues in an animation may be provided in many forms depending upon the instructional designers goals, however when adding signaling cues it is important to not add new information or alter the content of the instructional material (de Koning, Tabbers, Rikers & Paas, 2009). Similar to the inconclusive findings previously mentioned with motion and static animations, research is not yet conclusive in finding enhanced learning when comparing cued animations with non-cued animations (de Koning et al., 2009).

Determining which multimedia design feature: motion or static representations, and the inclusion or exclusion of signaled cues, have cognitive advantages for students in traditional high school classrooms are important research topics that need to be addressed. Evidence-based research with controlled experiments in natural contexts is preferred when providing recommendations for practitioners in the educational settings (Mayer, 2003). The research described hereafter will focus on establishing a need for
determining the educational effects of using multimedia presentations in high school classrooms, the theoretical constructs that form the foundations for effective multimedia design, a methodology modeled from established credible multimedia research, the statistical assessment designed to measure student understanding, retention, and synthesis of abstract science concepts taught with multimedia instruction, and the conclusions from this research.

**Need for Evidence-Based Studies in Traditional Classroom Environments**

According to Haslam and Hamilton (2010) understanding how student learning can be affected by cognitive load is essential when designing instructional materials. In order to facilitate learning one needs to limit the demands of working memory to a manageable level otherwise we risk inhibiting learning by overloading the cognitive abilities of the learner (Ayres, 2006a). Designing educational material that lowers the cognitive demands on the learner and facilitates comprehension and acquisition of newly learned materials is a high priority for teachers and instructional designers. For example, Bruning, Schraw, Norby, and Ronning (2004) suggested that multimedia material used in instructional environments should facilitate the working memory of students to assist deeper learning skills such as comprehending new concepts and using problem solving skills.

Research in cognition and pedagogy that is evidence-based and take into account the limitations of working memory has identified the importance of designing multimedia materials that do not overload the cognitive abilities of students and increase learner outcomes. This should guide which multimedia instructional material to use, when to use them, and how to use them effectively in the classroom (Moreno, 2007). In particular,
Mayer (2003) recommended that educational practice be based on evidence and stated “scientific research protects practitioners from implementing useless programs” (p. 361). However, it is not always obvious which educational practices have foundations in research and which come from assumptions, hunches, or recommendations by fellow teachers.

In the area of multimedia, Mayer (1997) and colleagues (Mautone & Mayer, 2001; Mayer & Moreno, 1998; Mayer & Moreno, 2002; Mayer, Moreno, Biore & Vagge, 1999; Moreno & Mayer, 1999) have contributed a wealth of research, much of which has been applied to educational contexts. The corpus of this work comprises the CTML and specific principles instructional designers can incorporate in multimedia content so learners can interact with the multimedia in the most cognitively effective manner. According to the CTML, multimedia may be defined as a presentation or representation that combines words with visual material (Mayer, 2005). The words may be spoken or in the form of written text, while the visual material may be a picture, movie, diagram, graph, or animation. One of multimedia instructional advantages is individuals have the ability to learn more from presentations which use visual and auditory components rather than those that use only a visual or auditory element (Clark & Paivio, 1991). The CTML guides the structure of multimedia content and instruction to take full advantage of how the brain processes incoming visual and auditory information for the purpose of creating quality multimedia instructional materials for learners.

The research establishing the main principles of the CTML has predominately been conducted with college-aged students in a laboratory setting with technical materials designed specifically for research, i.e., the designed text material (the inner workings of
car brakes, bicycle pumps, human lungs, and how lightning is formed) was for skilled, adults that spoke English and not applied to younger populations (McTigue, 2009). Additionally, much of the supporting research published on the effects of using static or dynamic animations within multimedia presentations also used college-aged participants, (see Boucheix & Schneider, 2009; Lin & Dwyer, 2010; Lowe, 2004; Mayer, Hegarty, Mayer & Cambell, 2005). Finally, an analysis of six top-tier psychology journals between 2003 and 2007 determined 67% of their publications used psychology undergrads in U.S. studies and studies conducted outside the U.S. used undergrads 80% of the time (Jones, 2010). Considering the limited research conducted on a precollege population, and the multimedia content used is not designed to meet the course curriculum at grade level but instead of a highly technical manner, a need to identify the most effective practices using evidence-based research is warranted for a younger population using grade level appropriate materials.

There is ample evidence that college age students and younger students exhibit numerous and important differences when learning from multimedia content. For example, children typically view illustrations as discrete items, while adults generally try integrating the visual information with corresponding textual information (Hannus & Hyona, 1999; Van Parreren, 1983). Similarly, when viewing a single graphical representation, adults tend to examine the image in a holistic manner, considering the entire image, whereas young learners tend to fixate on an isolated component of the visual representation (McTigue, 2009). Additionally, students with lower abilities tend to spend more time looking at the blank spaces between text and diagrams in science textbooks, while students with higher abilities locate important information more quickly
(McTigue, 2009). With respect to animation, novice learners will frequently focus on salient details instead of the larger theme (Moreno, 2007). These differences may be attributed to their lack of prior knowledge needed to identifying the most important content in a multimedia presentation as well as variations in the acquired learning skills.

In school settings, there is a preponderance of information delivered via multimedia to students everyday (e.g., visual aids found in science textbooks, electronic tablets, streamed video content, web pages, animations, and PowerPoint presentations). The cognitive demands for interpreting and integrating this information may be overwhelming for some students as Jones, Gardner, Taylor, Wiebe & Forrester (2010) reported. Experienced learners need less working memory to organize and integrate new information due to more robust schemas established in their long-term memories.

Generalizing the findings of research conducted with college students to that of an adolescent learner without conducting comparable evidence-based studies is not appropriate considering the identified differences between the two populations. This is an important educational issue Mayer et al. (2005) stated in their research comparing static and dynamic multimedia presentations with college students at a selective university. They commented, “the results might not generalize to population that includes lower ability or lower literacy individuals” (p. 264). Reiber (2005) pointed out “Generalization of the results from educational multimedia research to the “real world” of learning and performing in schools and the workplace should be viewed with considerable caution” (p. 551). To address this identified generalization issue evidence-based research is needed specifically with younger participants, engaged with multimedia instruction designed for the content they are exposed to, and in traditional classrooms settings to confirm or refute
the results derived from studies conducted with college students in laboratory conditions with highly technical multimedia content.

Currently a major emphasis has been placed on improving educational outcomes in Science, Technology, Engineering, and Mathematics (STEM). Trends in science courses to use virtual learning resources to supplement and in some cases replace traditional classroom instruction are expected to continue (Stull, Hegarty & Mayer, 2009) and teachers will play a pivotal role in determining what visual-spatial resources are brought into the classroom (Mathewson, 1999). The National Research Council (2006) set goals to promote spatially literate students that can use spatial thinking in informed ways (Jones et al., 2010). The research conducted here addressed the need to identify if animated or static images in a multimedia presentation have cognitive advantages within a population of high school science students in a traditional classroom setting.

**Spatial Ability**

Understanding visual representations in two-dimensional space from a three-dimensional world is an ability that varies between individuals. Piaget formed some of the foundations on visual-spatial thinking in children more than 60 years ago (Mathewson, 1999). As we reach puberty our capacity to understand abstract concepts grows and the higher order thinking associated with visual-spatial thinking also expands (Mathewson, 1999). Interpreting and manipulating visual information can place large demands on our working memory and depending upon one’s prior knowledge and spatial ability information conveyed in visuals may be limited by personal cognitive abilities. For novice learners material that imposes high extraneous load can overload their
working memory and result in diminished learning as compared to experienced learners (Hasler et al., 2007).

An interest in spatial ability differences has led to extensive research in cognitive science and visual spatial perception (see Churchland, 1995; Cornoldi & McDaniel, 1991; Hampson, Marks, & Richardson, 1990; Kosslyn, 1994; Kosslyn & Koening, 1992; Pinker, 1997; Ullman, 1996) and the ability to measure spatial ability (Jones et al., 2010; Shepard & Metzler, 1971; Vandenberg & Kuse, 1978). Numerous dependable assessments have been created and tested to measure spatial ability including the MVI-Shape Memory Test, SS2- Choosing a Path Test, The Storage Test, The Surface Development Test (Jones et al., 2010) and the Vandenberg & Kuse Mental Rotations Test (MRT) (Stull et al., 2009). Many of these spatial ability assessments have strong reliability coefficients and can be conducted in classroom settings in less than 30 minutes.

The MRT test used in this research and developed by Vandenberg and Kuse in 1978 has three sections that can be completed by most participants in less than 20 minutes and has a test reliability $KR20 = .88$ (Vandenberg & Kuse, 1978). The MRT test consists of 20 target objects each drawn in a three-dimensional representation. Each target is drawn with ten connecting solid blocks attached face to face, each image has three right angle bends, similar to an elbow bend in their structure so the final image is not linear, but instead has four distinct sections (Shepard & Metzler, 1971). Next to each target are four figures that look similar to the original; the two correct alternatives are represented in a rotated position along the Y-axis from the original. Participants must mentally manipulate and match the two acceptable figures that have been rotated on the Y-axis to the original target. The two distracters in the first 10 items are rotated mirror
images of the target image, and in the last 10 items the distracters are rotated of one or two of the acceptable figures (Vandenberg & Kuse, 1978). MRT scoring is by only accepting if the participant matches both acceptable rotated figures to the target, and no credit for matching just one, or matching one acceptable and one distracter. Scores range between 0 and 40 (Cherney & Neff, 2004; Vandenberg & Kuse, 1978).

**Foundations of the CTML**

The three guiding principles that form the foundation for CTML are: (a) the human mind is capable of processing information from two separate channels of incoming information, one for auditory and one for visual information, (b) the channels are limited in the amount and capacity to process the information, and (c) the individual must take an active role in coordinating the incoming information (Mayer, 2005). In order to process the information the learner first needs to be able to identify and select the relevant information, then organize the information into a schema, or mental representation within their working memory, and finally integrate the information with their existing knowledge stored in long-term memory (Hyunjeong, Plass, & Homer, 2006). Schemas can be defined as, “mental constructs that allow patterns or configurations to be recognized as belonging to a previously learned category and which specify what moves are appropriate for that category” (Sweller & Cooper, 1985 p.60). According to this final premise, in order for multimedia instruction to achieve results the learner must take an active role and make an effortful attempt to make meaning of the material presented. Mayer formed the CTML from the foundations of three theories describing the cognitive structure of the brain in terms of cognitive abilities, demands, and limitations: (a) Paivio’s dual coding theory, (b) Baddeley’s multi component model,
and (c) Chandler and Sweller’s cognitive load theory (Höffler & Leutner, 2007; Mayer et al., 1999; Reed, 2006).

Since Mayer formulated the CTML, numerous studies have been conducted to determine the best instructional design practices to build an effective multimedia tool. Principles such as the modality, redundancy, segmenting, signaling, spatial contiguity, and temporal contiguity principles each play a unique role in either limiting extraneous cognitive load or promoting effortful essential processing of the multimedia content (Mayer, 2009). Teachers and instructional designers taught to use the principles guiding Mayer’s CTML can utilize multimedia tools that leverage the cognitive abilities of the brain with the visual and auditory affordances that text, pictures, graphics, animation, video, and narration provide. For example, the addition of graphics multimedia instruction needs to be weighed carefully for the advantages of increasing cognitive processing in the visual regions of the brain, but also for the potential disadvantage of creating cognitive overload (Baddeley & Logie, 1999; Hanus & Hyona, 1999). The research presented here will help determine if animations representing motion or static images, and animations containing or excluding visual signaling cues, have significant effects on adolescent learners in traditional classroom settings.

**Instructional benefits of animation.**

As personal computers have become common in the home and classroom the use of animations as a source of instructional media has increased. Computers provide the recommended mode for using animation and narration in multimedia designs (Mayer et al., 2005). Animations can candidly and explicitly represent the movements or placement of abstract concepts (Kriz & Hegarty, 2007). As defined earlier, animations appear as a
sequence of rapidly changing computer screen or television images implying movement
to the user (Hoeffler & Leutner, 2007). The changing sequences may be used when trying
to teach concepts that have moving parts like an engine or brake system, or when the
objects are too large, small, or spaced apart for a single picture to represent.

Animations can be represented as static or dynamic in fashion. A static animation
contains visual images that do not represent change independently, but do represent
change from one image to the next. This leaves the interpretation of what has changed for
the learner to mentally animate any motion from one frame to the next (Kühl, Scheiter,
Gerjets, & Edelmann, 2011) whereas a dynamic animation represents some element or
movement from one frame to the next. Static sequential animation can be displayed in a
variety of styles. In some situations the images are presented side by side on the same
screen or page, referred to as integrated-sequential-static frame presentation (Boucheix &
Schneider, 2009) allowing multiple images to be seen at one time by the user and is
represented in Figure 1. The 21 screen shots in figure 1 are from a static signaled
animation showing the moon make one complete orbit around the earth.
Figure 1. Integrated-Sequential-Static Frame Example
Figure 1 demonstrates the cognitive demands that can be experienced when engaging in a long detailed multimedia presentation. The earth is rotating as can be inferred by the change in position of the continents and the moon is represented as a half white disc. This white disc represents the part of the moon reflecting the sunlight. The moon also becomes smaller as it passes behind the earth and than appears larger as it returns to the original position. Finally, the earth and stars move slightly in this representation in relation to the sun, but the sun remains fixed. When only a few visuals are necessary this design strategy is effective, however when the educational concept is complex requiring many images as the content in this research required, this design is less effective.

With abstract and complex concepts a second option is to have static frames appear independently and sequentially to the other frames. In this situation, referred to as sequential-independent-static frame representation (Boucheix & Schneider, 2009) when one static image disappears the next sequential image appears. After a predetermined length of time the second image disappears and the next sequential image appears and so forth. When comparisons between static image animations and dynamic animations are conducted it is necessary to limit information non-equivalence identified by Tversky et al. (2002) and Mayer et al. (2005) by including static images that represent essential changes in information (i.e., relevant changes in motion, time, structure, color, shape, texture). In the example represented in Figure 1, 21 images are used with five static images between each moon phase. This provides the learner ample opportunity to interpret and select the important information. However, if only four images in total were
included e.g., half moon, full moon, half moon, and new moon significant visual information would be left out creating an information nonequivalence situation.

In both examples of static image representation explained here, movement does not occur within a frame but does occur from one visual representation to the next visual representation. The cognitive benefit gained using static animations comes from the learners actively processing the differences between the sequential frames (Hoeffler & Leutner, 2007; Mayer, 2005, 2009). However, if mentally animating the material is difficult then extraneous cognitive load will be high and potentially overloading (Kühl et al., 2011). As long as the cognitive load is managed and not overly demanding, an active student may learn more than someone passively watching a dynamic animation.

Dynamic animations represent a contextual change from one frame to the next. Contextual changes come in the forms; change in size, shape, color or textures are referred to as transformational, the movement of entire entities is translational, and the appearance or disappearance of an entity is referred to as a transitional change (Lowe, 2004). Depending upon the amount and degree of contextual change in the dynamic animation, motion may create large cognitive demands and overload the student’s working memory (Ayers & Paas, 2007). Research has indicated that the cognitive demands associated with processing these changes are highly correlated with visual and spatial abilities (Cornoldi & Vecchi, 2003; Hegarty & Kozhevnikov, 1999; Hegarty & Sims, 1994). These cognitive demands may be decreased with sound instructional design that incorporate some, or all of the identified multimedia design principles identified by CTML research (Mayer & Moreno, 2002).
Instructional benefits of video, pictures and text.

Television and films have been used in classrooms for decades. With the advent of the videocassette recorder (VCR), the digital videodisc (DVD), and most recently streaming content directly from the internet even more multimedia opportunities have become available to teachers and educational designers. In the form of a recorded DVD additional affordances arise from the television format. If the user is able to access the menu options then there is a non-linear structure and an interactive opportunity arises between the user and the media (Schwan & Riempp, 2004). This interactive ability theoretically allows the user to adapt the presentation to his or her individual cognitive needs by allowing them to skip over, rewind, or pause the video presentation (Schwan & Riempp, 2004). This interaction can be leveraged in multimedia presentations with the segmentation principle.

Few would deny the positive outcomes associated with reading, however there are certain obstacles that must be overcome by a student to fully comprehend written text. Reading comprehension is a multi step process where the student has to have phonological awareness that the words are composed of component sound, and decode the word in a format of a visual printed symbol into a sound (Mayer, 1998). Additionally, readers have to use their prior knowledge of the semantics and syntax of the words, make meaning of the word in the context of the sentence and paragraph, plus applying the grammatical rules requires skill and practice (Mayer, 1998). As readers become more proficient this process becomes automatic, but for some learners and low ability students in the K-12 setting this can be a cognitively demanding process. Professionals associated
with education today understand students come into the classroom with a wide variety of reading abilities.

**Adolescent Cognitive Skills and Prior Knowledge**

One aspect the CTML does not directly take into consideration is the age and development of the user. Prior knowledge and working memory capacity are often significant factors contributing to the effectiveness of the redundancy, segmenting, signaling, spatial contiguity, and temporal contiguity principles (Mayer, 2005). Much of the research conducted on these principles was with college-aged participants (McTigue, 2009) and determining whether the same benefits can be generalized to other populations is important.

Novice learners with less prior knowledge may use less effective learning strategies than older more experienced learners. Novices have difficulties identifying the most important parts to attend to while viewing animations, thus creating situations where the learner will often focus on details they perceive as salient but may not be relevant to the overall theme (Moreno, 2007). Research in instructional design has demonstrated that design elements beneficial to expert learners may not be effective for the novice learner (Ayres, 2006a). The lessons learned from the research conducted in the CTML by Mayer and his co-researchers is not generalizable to a typical classroom because they often used older participants, with higher reading abilities, and their multimedia content was more technical than the more general information found in school textbooks (Segers, Verhoeven & Hulstijn-Hendrikse, 2008). The differences between the parameters in this established research and what is found in a pre-college
environment has created a need for specific research in this area (Mautone & Mayer, 2001; Segers, et al., 2008).

**Software**

This research project used *Anime Studio Pro 7* to develop both a series of sequential-independent-static frame animations and dynamic animations. Each of the animations contained identical narration and operator control options to pause, rewind, and continue. The static animation displays a static image for a predetermined amount of time, then disappears and the next static frame appears for a predetermined amount of time. The static images in this research were copied directly from the dynamic animation and spaced in time so the presented visual and audio information is equivalent with the exception of the movement observed in the dynamic animations. This design of using the same narration, controls, and images should limit the informational nonequivalence identified in previous comparison research (Mayer et al., 2005; Mayer, 2009; Tversky et al., 2002).

The animations in this study were longer than many of the multimedia presentation research used by Mayer and his co-workers (e.g., the 2.5 minute multimedia presentation with 16 PowerPoint slides, and the 80 second presentation containing 8 slides used by Mayer and Johnson (2008), the 60 second presentation used by Mayer, Fennell, Farmer, and Campbell (2004), the 30 and 45 second multimedia presentations used by Mayer and Anderson (1991), or the 140 second animation broken into 16 segments used by Mayer, Heiser and Lonn (2001)). This longer, more detailed presentation containing some repeated concepts represented a more realistic scientific presentation found in high school science course. Abstract concepts such as the
gravitational pull from the Sun and Moon create different tidal conditions on Earth. The tide coincides with the phase changes of the Moon and is difficult to visualize, as this requires spatial understanding as well as a concept of progression through time. The software used, *Anime Studio Pro 7* provided the ability to incorporate these complex interactions on different layers and then render them together in one final presentation (Murdock, 2010). The audio channel allowed narration to correspond to the animation so the participants had no text to read with the exception of the one or two words used in the treatments using signaling. This software allowed the affordance to incorporate the principles from the dual channels of visual and auditory processing proposed by Paivio and Baddeley (Mayer, 2005).

The multimedia presentation used described the complex interactions in both time and space of the Moon and Sun’s gravitational effect on the Earth. The complex interactions focused on the monthly orbit of the moon and the tidal variations created by the Moon and Sun’s gravitational pull. For each of the four treatment conditions (i.e., motion with signaling, motion without signaling, static with signaling and static without signaling), three animations from different spatial perspectives were created to represent the interactions among the Sun, Earth, and Moon. These varying viewpoints provide the viewer a depth of field, side view, and polar view. Three examples of a signaled and non-signaled screen shot from each of the three view points can be seen in Figures 2, 3, 4, 5, 6, and 7. All the screen shots used in the static signaled treatment along with the transcribed narration for the corresponding image can be found in Appendices A, B, and C. Figures 2 and 3 display a depth of field perspective of the Sun, Earth, and Moon and all nine of the static signaled screen shots from this one minute and 35 second portion of
the animation are found in Appendix A. Figures 4 and 5 display a side view of the earth and moon with all nine static signaled screen shots from this one minute and 26 second portion of the animation are found in Appendix B. Finally, Figures 6 and 7 display a polar view perspective of the Sun, Earth, and Moon and all 12 of the static signaled screen shots from this one minute and 52 second portion of the animation are found in Appendix C.

Figure 2. Static Non-signaled Depth of Field View Image.
Figure 3. Static Signaled Depth of Field View Image.

Figure 4. Static Non-signaled Side View Image.
Figure 5. Static Signaling Side View Image.

Figure 6. Static Non-signaled Polar View Image.
Goals of this Study

This study was designed to measure the benefits of using animations containing motion with signaling or without signaling compared to static image animations with or without signaling cues. The evidence-based research design and dependent measures addressed three main research questions: (1) How does motion in multimedia science instruction impact students’ learning? (2) How does signaling in multimedia science instruction impact students’ learning? (3) While controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to learning from multimedia presentations?

The first research question stems from the static media hypothesis that according to Mayer et al. (2005) is addressed within the CTML. The static-media hypothesis asserts that there is a cognitive load advantage when a student interacts with a static image and
written text versus a moving image with narration (Mayer et al., 2005). This can be explained, as static images are less cognitively demanding as the participant does not have to attend to the moving parts inherent to animations containing motion. By displaying each static image in a sequential series the participant is likely to use active processing to identify changes from one image to the next (Mayer et al., 2005). A decrease in extraneous cognitive load should translate to an increase of generative processing (i.e., used to process images and make meaning to the visual information in the images) for participants viewing static pictures. By contrast, attending to the salient details of a continuously changing animation with motion may likely create more cognitive demands placed on the learner than when viewing static images (Kalyuga, 2008; Kriz & Hegarty, 2007; Mayer et al. 2005).

The second research question addresses the role of signaling in multimedia learning. The presence of signaling may reduce the cognitive load to sufficiently offset the previously documented negative effects illustrations seem to place on lower ability students (McTigue, 2009), however current analysis of research with visual cueing has not identified which presentation parameters provide effective results (de Koning et al., 2009). Signaling consists of creating a visual cue designed to focus a student’s attention (Moreno, 2007). Visual signaling examples may be highlighting a specific area of the graphic image you would want the viewer to notice, enlarging important images within the graphic, making important images blink in the graphic, or flashing a short text that labels an important interaction or step in a process.

Because it is not necessarily clear from previous research how animations with motion or animations with static images, and signaling may impact adolescents, a third
question will be addressed in this research project: While controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to learning from multimedia presentations? This would imply that animations that included the same CTML principles of modality, segmenting, spatial contiguity, temporal contiguity, and redundancy while only varying degrees of motion and signaling create an instructional environment where no significant differences in student retention and construction of knowledge of science concepts be measured.
CHAPTER 2

REVIEW OF THE LITERATURE

The Cognitive Theory of Multimedia Learning (CTML) has a large body of established research that Mayer has used to develop the theory. The three theories describing the cognitive structure of the brain in terms of cognitive abilities, demands and limitations forming the foundation to CTML are: (1) Paivio’s dual coding theory, (2) Chandler and Sweller’s cognitive load theory, and (3) Baddeley’s multi component model (Mayer 2005, 2009). Additionally, Mayer and Moreno (2002) identified principles to apply while designing multimedia instructional materials. The CTML, along with the Integrated Text and Picture Comprehension Model and Multimodal theory, are the prevailing theoretical explanations describing how the brain processes visual and auditory information (Mayer, 2005; Reed, 2006).

Dual Coding Theory

The constructs established in Paivio’s dual coding theory provide vital components to designing effective multimedia instruction. Dual coding theory proposes that the brain has two separate channels, or pathways to process information: an auditory channel and a visual channel (Clark & Paivio, 1991; Reed, 2006). Each channel has a limited capacity to receive information by sensory perception in either an auditory or visual form. For the CTML, this is an essential component as information can be presented in both modalities and with well-planned instructional design one can leverage the two processing systems, which should increase the learning potential (Mayer et al., 1999). Instructional designers using multimedia interactions must limit the amount of information necessary to process in either of these channels at any one time or risk
overloading the cognitive abilities of the student (Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). Instruction that leverages the processing abilities of the cognitive structure in the brain by allowing two separate types of sensory information (visual and auditory in the case of multimedia instruction) has clear advantages compared to instruction that only addresses a single mode.

Dual coding theory should not be considered a one-way process though. While there are separate regions to process incoming information, each region can also retrieve non-verbal and verbal information (Harskamp, Mayer & Suhre, 2007; McTigue, 2009). This retrieval can facilitate the learning potential of the individual. An example may be a student learning about an abstract concept such as the double helix structure of the DNA molecule may create a visual analogy of a twisted ladder to help understand the concept better (McTigue, 2009). The ability for information to be accepted and retrieved by two separate channels provides the learner with an ability to process and recall not only more information, but also potentially more abstract and complex information for processing. This is a key cognitive advantage when using multimedia instruction in math and science courses as they often teach abstract concepts that requires more working memory to comprehend and process new information.

**Cognitive Load Theory**

Research indicates that the brain can only process a limited amount of concurrent information. In the case of the CTML, information is perceived via the senses in two main forms through working memory (i.e., visual and auditory information) (Kombartzky, Ploetzner, Schlag, & Metz, 2010; Reed, 2006). Within working memory, we either rehearse and or elaborate the information to make connections in our long-term
memory or the information is lost or decays (Miller, 1956). By rehearsing and elaborating we may keep information in our working memory for longer periods of time, but eventually if we do not make meaning or connections to existing knowledge within our long-term memory this information will be lost (Lusk Evans, Jeffrey, Palmer, Wikstrom & Doolittle, 2009). Long-term memory in contrast to working memory has a larger capacity and appears to be almost limitless (Chase & Simon, 1973; Newell & Simon, 1972). Recalling information stored in long-term memory can help decrease the cognitive load demands limited in working memory. Long-term memories are often represented as schemas, or mental representations we have already established and can be recalled under varying degrees of automaticity (Leahy, Chandler & Sweller, 2003; Kombartsky et al., 2010).

The ability to make connections and learn new information relies on the ability of the individual to process the sensory information coming into working memory and either connect it to prior knowledge or make new meaning to it before being lost. Working memory capacity in the brain varies among individuals but appears to be controlled by three different forms of cognitive load demands: intrinsic, extraneous, and germane loads (Chandler, 2004; Chandler & Sweller, 1991; Höffler & Leutner, 2007; Sweller, 1994). The intrinsic load is determined by the difficulty of the material being represented and is not under the control of the instructor or instructional designer. The extraneous load is determined by how the material is presented and is under the manipulative control of the teacher or instructional designer. If the intrinsic and extraneous loads are both high then the limited capacity within the working memory may be over loaded (Höffler & Leutner, 2007). By decreasing the extraneous load through sound instructional practices the
learner can exert more energy into the third type of cognitive load, germane load. Germane load is where the effortful processing Mayer refers to in the CTML is necessary to maximize the benefits of multimedia learning (Mayer, 2005). As students engage in the learning process by integrating the visual and verbal information with prior knowledge a generative process occurs (Mayer, 2009). The more working memory capacity left for generative processing, the more construction, and automation of schemas can occur and this theoretically leads to enhanced learning (Kalyuga, 2011; Mayer, 2009).

**Multi-Component Model**

Cognitive load theory is based on a human cognitive infrastructure and plays an integral role in building the theoretical foundation upon which Mayer based the CTML. Our cognitive memory structure has three components: sensory memory, long-term memory, and working memory (Sweller, 1994). Sensory memory is constructed from information perceived by the five senses with visual and auditory perceptions the primary sources. Long-term memory develops over a lifetime as we learn new concepts and then store them for later retrieval. Working memory is more fleeting and limited than long-term memory. The two major limitations of working memory are the capacity to do work and duration one can hold the information in working memory (Mayer, 2005). Miller’s seminal work in 1956 revealed that working memory’s capacity of an individual is able to hold about seven elements of information at a time. Of these seven pieces of information our working memory can only process or manipulate between two and four of these items (Miller, 1956). The duration, or length of time someone can use the information within working memory is also limited to approximately 20 seconds (Peterson & Peterson,
The limitations of working memory vary among individuals, however this memory can be expanded within limits by chunking and using rehearsal strategies (Miller, 1956).

Working memory is believed to be where the bulk of the mental processing occurs when students engage themselves in a learning process. The CTML applies the multi-component model from Baddeley and Logie (1999) to explain how working memory functions within the CTML (Mayer, 2005; Mayer, 2009). The multi-component model has four separate mechanisms working together within working memory: (1) a central executive, (2) the visuo-spatial sketchpad, (3) an auditory-based phonological loop, and (4) an episodic buffer (Baddeley, 2000, 2001; Baddeley & Logie, 1999; Reed, 2006). The central executive is believed to coordinate the activities within the working memory. The visuo-spatial sketchpad stores both visual and spatial information for short periods of time and helps recreate mental images, while the phonological loop stores and rehearses verbal information by articulation. Finally, the episodic buffer is believed to combine and assimilate the information in the visuo-spatial sketchpad with the content within the phonological loop and our long-term memories (Baddeley, 2000).

The Cognitive Theory of Multimedia Learning

The CTML has been revised slightly over the years to account for new information discovered from research conducted by Mayer and his colleagues but the overall theoretical foundation has remained relatively unchanged. By using the visual and audio channels of the brain and connecting incoming information to prior knowledge already stored in long-term memory, or using available generative processing to make new connections, the CTML has cognitive advantages over instruction dominated by
either listening to a lecture or reading from text. The theoretical foundations Mayer (2005, 2009) used to describe the CTML applies the core assumptions from the dual coding theory, cognitive load theory, and multi-component model discussed earlier with five independent processes that occur with an active learner engaged in multimedia instruction. The following five steps do not have to occur in a linear fashion and the learner may even use some of the steps multiple times during a multimedia lesson depending upon the individual’s prior knowledge, working memory capacity, and the cognitive load of the lesson. According to the CTML the five steps active learners engage in are: (1) selecting relevant visuals for processing, (2) selecting relevant words for processing, (3) actively organizing the selected visual information into a pictorial mental model, (4) actively organizing the selected words into a verbal mental model, and (5) combining the pictorial and verbal models with ones’ prior knowledge stored in long-term memory (Kalyuga, 2011; Kombartzky et al., 2010; Mayer, 2005, 2009).

The CTML is based on a knowledge-construction perspective where the learner is engaging as an active participant trying to generate mental representations from a multimedia presentation (Mayer, 2005, 2009). The five steps an active learner engages in during multimedia learning depends on the learner having the generative capacity to select, organize and combine relevant visual and verbal information in order to construct new knowledge. Effective use of the CTML is dependent on the instructional designer’s understanding of the cognitive structure of the brain: (a) dual coding theory, allowing for two separate pathways for incoming information to be processed; (b) multi-component model, allowing for a theoretical explanation of how the architecture of the brain can process and combine the sensory audio and visual information with prior knowledge.
stored in long-term memory; and (c) cognitive load theory, describing the brain’s limitations on how much information can be processed (Leahy et al., 2003; McTigue, 2009; Park, Lee & Kim, 2009; Reed, 2006). In order to maximize the cognitive benefits of using visual and auditory information and combining this with one’s prior knowledge, the CTML suggests designing multimedia instruction that takes into consideration the cognitive abilities inherent to working memory.

While the CTML theoretical foundations has changed little since Mayer introduced the CTML a few explanatory components have changed with new information revealed from experimental research. In Mayer’s first edition (2005) of *The Cambridge Handbook of Multimedia Learning* forty-five experimental comparison research studies were used to explain the principles that formed the CTML, in Mayer’s (2009) *Multimedia Learning; Second Edition* there are ninety-three experimental comparisons (Mayer, 2009). One significant change to the CTML comes from recent insights into the types of cognitive load a learner encounters in a multimedia presentation. Cognitive load can be defined as “the load that performing a particular task imposes on the cognitive processing system” (Haslam & Hamilton, 2010, p. 1717). The mental effort required to process a task and the mental load imposed by the task itself are both factors contributing to cognitive load. The cognitive load divisions of intrinsic, extraneous, and germane load found within working memory affect the cognitive processing ability of the learner. This processing is divided into essential, extraneous, and generative processing is defined in the triarchic model of cognitive load (Deleeuw & Mayer, 2008; Kalyuga, 2011; Mayer, 2009).
In the triarchic model the extraneous cognitive load placed on learners from ineffective or inefficient instructional design places demands on the learner forcing them to expend working memory capacity to process the information in a meaningful way. This form of cognitive processing called extraneous processing does not benefit the learner and originates from poor instructional design (Mayer, 2009). An instructional design that places a diagram in one location but the explanation of the diagram in another, or plays a narration before presenting the corresponding animation instead of combining the narration with the animation leads to extraneous processing (Mayer, 2009). If the instructional design is poor and consumes all of the learner’s available working memory capacity then they will be restricted from selecting, organizing, and integrating the multimedia content. Understanding and limiting extraneous processing when possible is essential to the CTML as it describes an active learner as one who selects important visual and verbal information, and organizes this information in a mental model that can be integrated with their prior knowledge.

The second type of processing, essential processing in the triarchic model is linked to intrinsic load. The more complicated the content presented, the more essential processing is required selecting the important material. The essential processing as described in the CTML predicts this is where the learner selects relevant visual and verbal information and holds this represented material in working memory (Kalyuga, 2011). When engaged primarily in essential processing in a multimedia presentation the outcome is likely to be higher rote learning as measured in retention assessments but poor transfer performance (Kalyuga, 2011; Mayer, 2009).
The third and final part of the triarchic model described by Mayer (2009) is related to germane cognitive load and is referred to as generative processing. When engaged or motivated students are actively organizing their selected visual and verbal representations into a mental model and then integrating this with their prior knowledge they are using generative processing (Kalyuga, 2011). When a learner uses both essential and generative processing during a multimedia presentation they are more likely to select, organize and integrate relevant information with their prior knowledge stored in long-term memory. The ability to combine these two cognitive processes is more likely to lead to deeper and meaningful learning measured by good retention and transfer of knowledge (Kalyuga, 2011; Mayer, 2009).

The CTML accounts for the three cognitive demands placed on a learner with a viable explanation that lead to triarchic model’s description of extraneous, essential, and generative processing. Additionally, the CTML provides instructional design suggestions to reduce the demands in working memory so an increase in essential and generative processing can occur resulting in higher learner outcomes in both retention and transfer. The suggestions, or principles as they are called have been tested in multiple experiments that compare a group of participants that learn from a multimedia presentation containing a particular principle to a group who receives a similar presentation without the principle. Research from Mayer and his colleagues have indicated that the demands on extraneous cognitive processing can be decreased by incorporating the principles of redundancy, signaling, spatial contiguity, and temporal contiguity (Mayer, 2009). The essential processing can be manipulated by using signaling and modality principles and finally, using the multimedia principle can promote generative processing.
In summary, a strong foundation for Mayer’s CTML is provided from the combinations of the theoretical constructs within the dual coding and cognitive load theories, and the multi-component model. These theories provide a basis to addresses the cognitive load limitations learners are likely to experience with multimedia presentations within working memory. Additionally, within the CTML the triarchic model of cognitive load describes the cognitive processes occurring in the brain during a multimedia learning experience. An active learner using essential cognitive processing selects relevant visual and auditory content. If the multimedia presentation is not overly cognitively demanding, which would require extraneous processing, a learner can use available germane processing to organize and integrate a developing mental model with prior knowledge stored in long-term memory. The last key component for the CTML entails designing multimedia instruction using principles established from evidence-based experiments that do not overload the working memory with extraneous processing. The incorporation of instructional design principles that fosters essential and generative processing will lead to increased learner outcomes in retention and transfer performance.

**Cognitive Theory of Multimedia Learning Design Principles**

The design of effective multimedia instruction should be structured from a learner-centered approach where the designer takes into account the learner in the classroom, the learning environment, and the type of media used (Mayer & Moreno, 2002). Learners may differ by age, working memory capacity, prior knowledge, motivation, or reading ability. While the individual variations of the participants in a multimedia-learning environment might differ along a wide spectrum, the instructional design characteristics demonstrated to show positive results do not vary as much. By
adhering to specific instructional design principles the learning environment can be enhanced when incorporating the multimedia formats of animation, video, narration, and text into presentations (Mautone & Mayer, 2001; Mayer et al., 2005; Mayer & Johnson, 2008; Mayer & Moreno, 1998; Mayer & Moreno, 2002; Moreno, 2007; Moreno & Mayer, 1999, 2006). As a result of extensive evidence-based research instructional design principles have been demonstrated to decrease extraneous processing and foster essential and generative processing (Mayer, 2009). Multimedia principles known to decrease extraneous processing include the principles of: split-attention, redundancy, signaling, spatial contiguity, and temporal contiguity. The modality and segmenting principles are known to promote essential processing and the multimedia principle encourages generative processing (Mayer, 2009).

**The modality principle.**

The modality principle has been well studied and results indicate that when multimedia presentations contain animations along with a narration instead of animations with written text learning is enhanced (Mayer & Moreno, 1998; Mayer, 2009). Research conducted with math and science based lessons have consistently demonstrated enhanced learning when narrations were used instead of printed text (Jeung, Chandler, & Sweller, 1997; Lowe & Sweller, 2005; Moreno & Mayer, 1999). The modality principle stems from the theoretical foundations established in the dual code theory, the brain has two channels to process information, (Clark & Paivio, 1991; Reed, 2006) and the multi-component model that describes a visuo-spatial sketch pad processing visual material and a phonological loop processing the audio material (Baddeley, 2000). Instructional design should utilize both visual and auditory channels instead of potentially overloading the
visual channel with pictorial information and written text to process. Mayer (2009) reports positive results with a median effect size of 1.02 from seventeen experiments designed to test the modality principle when information is presented with illustrations or animations with narration compared to illustrations or animations with written text.

The modality principle is particularly beneficial with content that has high intrinsic load, as is often the case with math and science classes. Due to the limited capacity of working memory (Sweller, 1994) the intrinsic load placed on a learner is usually fixed but the extraneous load, which is created by the presentation style, can be manipulated. By narrating instructions or explanations alongside visuals instead of providing text along side the visuals the extraneous load can be reduced (Mousavi, Lowe & Sweller, 1995) and by off-loading some of the cognitive demands from the visual channel to the auditory channel more essential processing can occur to select the important information (Mayer, 2009). The modality principle has also been identified as beneficial to individuals with limited prior knowledge or poor reading skills. By decreasing the cognitive demands in working memory these learners have more capacity to process the information and create a mental model (Kalyuga, 2008).

The redundancy principle.

The redundancy effect occurs when the same information is presented in two formats either at the same time or in close proximity to each other. According to Sweller (2005) this may occur in two ways: (1) when additional information is added to elaborate on a concept such as comparing a summarized text to the full text, or when multiple pictures and diagrams of the same phenomenon are used, and (2) duplicate information is presented using two or more types of media, such as representing words in a narrated and
written form, or pictures and words representing the same material. The redundancy effect is believed to place more demands on working memory as the learner tries to coordinate the two sources of redundant information (Sweller, 2005).

Research has shown instructional design that addresses the redundancy principle may help increase learner outcomes compared to multimedia designs where this principle was ignored (Mayer & Johnson, 2008). Moreno and Mayer (2006) determined in a science based lesson where synchronized diagrams and redundant auditory and visual text information was presented student performance on retention and transfer tests were lower than for students that did not receive redundant auditory and visual text material. This research found multimedia instruction that presents an animation while simultaneously presenting a narration accompanied with written text (both explained the animation) lowered student comprehension, compared to those that saw the animation first, and then heard the narration with the printed text explaining the animation. Moreno and Mayer (2006) reported a split-attention effect might have contributed to lower comprehension scores in this study. With three pieces of information presented simultaneously the extraneous load was elevated as students had to process information presented as animation, narration, and written text to understand the concept. However, when the animation was viewed first, followed by the narration and visual text the students had time to process the animation initially and then could attend to the narration and visual text. Separating the redundant material allowed the participants to process each component individually with the dual coding ability of the brain (Moreno & Mayer, 2006).
A significant aspect to take into consideration while designing multimedia presentations concerning the redundancy effect is the prior knowledge of the students. When individuals with higher prior knowledge are provided with detailed instructions in a multimedia presentation parts, or all of the instructions may be redundant with information they already have in their long-term memories. These individuals must either ignore some or all of the instructions, or integrate this material with their existing stored schemas, otherwise they can experience elevated extraneous load (Kalyuga, Ayers, Chandler, & Sweller, 2003). Novices on the other hand often need detailed instructions when first learning a new skill or concept. This paradox of a situation being beneficial for one type of learner but detrimental to another is referred to as the expert reversal effect (Kalyuga, 2008). The expert reversal effect has been demonstrated when novice trainees benefited by using instructions that contained integrated textual and visual instructions while experienced trainees did better with diagram only instructions (Kalyuga, Chandler, & Sweller, 1998). In situations where the instructional designer knows the prior knowledge of the students they are advised to take the expert reversal effect into consideration whenever possible. Novice learners need more instructions that may require combining visuals with narrations while those with more prior knowledge may require a simplified format so they are not required to integrate the new information with their existing schemas.

**The segmenting principle.**

The segmenting principle can be beneficial when multimedia instruction contains high intrinsic and extraneous load. By dividing the presentation into smaller segments and allowing the user to interact with the stop, rewind, and play options extraneous load
within working memory may be reduced and deeper learning can occur (Lusk et al., 2009) allowing the student to organize visual and audio information into a mental model (Mayer, 2009). The theoretical rationale for the segmenting principle is derived by allowing the user to regulate the pace of material they find cognitively demanding which provides them an opportunity manage their cognitive load as they select relevant visual and audio content as smaller chunks of information (Hasler et al., 2007; Park et al. 2009).

Just as the redundancy principle has varying individual effects depending upon the prior knowledge of the learner, the segmenting principle may also have similar individual difference variables depending upon the prior knowledge and working memory capacity of the learner (Chandler & Sweller, 1991). Previous research has demonstrated that individuals with lower prior knowledge and less working memory capacity can show increased learner outcomes from multimedia presentations that incorporate the segmenting principle (Lusk et al., 2009; Park et al., 2009). By using the segmenting principle and taking the participants prior knowledge into consideration instructional designers can increase the educational gains of students engaged with the multimedia content (Boucheix & Schneider, 2009; Lowe, 2004; Moreno, 2007; Schwan & Riempp, 2004).

**The signaling principle.**

Signaling cues that direct the learners’ attention to important information is another technique instructional designers and educators can use with multimedia instruction (Mautone & Mayer, 2001; Moreno, 2007). Signaling can be accomplished in a multitude of ways depending upon the type of media discussed so far. Underlining key sentences in a passage, highlighting key words in a section of text, diagram, or graph,
blocking or graying out visual information in a dynamic or static animation are just a few examples of signaling. Mayer (2005) reported on two studies (Harp & Mayer, 1998; Mautone & Mayer, 2001) designed to measure the positive cognitive benefits of using signaling practices within multimedia instruction. Harp and Mayer (1998) used a paper based multimedia presentation that contained text and diagrams describing the formation of lightning. Mautone and Mayer (2001) used animations with narrations explaining how airplanes achieve lift. Both research studies found positive effects but Mayer (2005) points out the effect size was small and the amount of relevant research on this topic is limited.

The signaling effect is believed to decrease the cognitive processing in working memory by drawing the attention of the student to the most important details (Mautone & Mayer, 2001) instead of using extraneous processing to integrate nonessential material (Mayer, 2009). When intrinsic load is high and the amount of material presented in the multimedia presentation is also high signaling may decrease the amount of searching required by the participants. However, if the extraneous load is not complex or if the intrinsic load is not high then using signaling may not be beneficial or even act as a distracter to the user (Harp & Mayer, 1998).

**The spatial contiguity principle.**

The spatial contiguity effect occurs when designers place corresponding words and pictures near each other rather than apart, (Mayer, 2005). Once again these principles help lower the cognitive demands within the working memory of the student. By placing text and diagrams, or narrations and animations together the student does not have to hold
information in their working memory while they search or wait for corresponding information.

There is a large amount of research demonstrating higher learner outcomes in terms of retention and transfer by placing text and visual material close to each other instead of on separate pages, or even in different areas on the same page. In one research study Mayer (1989) placed instructions near the corresponding diagrams for a lesson describing how brakes work for one group and placed the instructions at the bottom of the page with the corresponding diagram for another group. In this early experiment designed to measure the spatial contiguity effect Mayer found the group receiving the instructions and diagrams together could transfer more information on a post-test than the group receiving the separated instructions and diagrams (Mayer, 1989). Sweller, Chandler, Tierney, and Cooper (1990) determined that placing math symbols describing each step near the corresponding diagram increased transfer scores on a post-test compared to the group that had the symbols and steps below the diagrams (Sweller et al., 1990). Tindall-Ford, Chandler, and Sweller (1997) found students learned to solve practical problems better when they received instructions that placed text near diagrams as compared to students who received instructions where the text was placed below the diagram (Tindall-Ford et al., 1997). The common theme in this research is by placing relevant corresponding materials spatially near each other participants do not expel valuable processing capacity searching and holding information in their working memory, extraneous processing. Instead of consuming working memory on search and find behavior more essential processing is available for effortful learning.
The temporal contiguity principle.

The temporal contiguity effect occurs when multimedia presentation containing narration and animations or video do not time the narration to coincide with the animation or video. Presentations or materials that require individuals to retain material in working memory while they wait to hear or see corresponding material increases cognitive demands. The temporal contiguity principle suggests incorporating narrations with animations so the learner can use their dual coding ability more effectively, will reduce cognitive demands.

The temporal contiguity principle has numerous research studies demonstrating cognitive advantages when used correctly. Mayer and Anderson (1991, 1992) demonstrated with transfer tests that students engaged with an animation that was synchronized with a narration explaining how a tire pump worked scored higher than students engaged with an animation that had the narration played before or after the animation (Mayer & Anderson, 1991). This research was replicated when they used the same format, narration with animation versus narration before or after narration with a lesson explaining how the brakes of a car work (Mayer & Anderson, 1992). Similar results were reported by Mayer and Sims (1994), and Mayer et al. (1999) when they combined or separated animations with narrations while using science lessons to teach about the human respiratory system and lightning formation.

The principles summarized here have all shown that when incorporated correctly learners can benefit from multimedia instruction. The CTML takes into consideration and incorporates the cognitive structure of the brain described by the dual coding, cognitive load, and multi-modal theories to describe the most effective way to design multimedia
instruction. Critical to the instructional design of educational material for students is an understanding of the impact cognitive load has on student learning (Haslam & Hamilton, 2010). Using the principles of modality, redundancy, segmenting, signaling, and spatial and temporal contiguity with the appropriate media can increase learner outcomes in retention and transfer when the user is engaged.

**Other multimedia models.**

Mayer is not alone in proposing a theoretical model based on established cognitive research to advance multimedia education in the classroom. Schnotz (2005) and Engelkamp (1998) both proposed theoretical models based on a cognitive architecture that addresses increasing learning in the classroom while using multimedia instruction. Each theory has many components similar to Mayer’s CTML but each also has a slight variation based on the mental representations constructed or performed by the learner. An overview of each of these theoretical models follows.

**Integrated Text and Picture Comprehension Model**

The Integrated Text and Picture Comprehension Model (ITPC) has many similarities with Mayer’s CTML (Mayer, 2005). Each relies on the dual coding ability of the brain to process auditory and visual sensory information separately, both assume an active learner, and both account for a limited capacity within the working memory of an individual. The difference is in how they define sensory information and how this is processed in the dual channels. The ITPC model’s theoretical construct is language is not always auditory, often times this is in a written text format, and not all visual information is associated with visual perception, but instead may be interpreted by other modalities (such as sound images) (Mayer, 2005). According to Schnotz the ITPC model accounts
for variations of sensory information and claims working memory has a filter redirecting the information to the correct coding region. When an individual reads text the information comes in through a visual channel, but the auditory channel is where words are decoded. According to the ITPC model this visualized text material is filtered between the perceptual level and the representational channels within our working memory (Mayer, 2005). An audio sound of a bird whistling or a car honking a horn would similarly come in through the audio perception channel but then be filtered to the visual representational channel in working memory.

The second construct that differs between the CTML and ITPC concerns the construction of a mental model by the learner. In Mayer’s CTML the final mental model is constructed by integrating the pictorial and auditory information with prior knowledge within working memory. Schnotz’s ITPC asserts the integration of information from the visual and auditory channels occurs before going into working memory. Once in the working memory, the information can be linked to prior knowledge and here is where a final mental model is formed (Mayer, 2005). The CTML and ITPC models are similar in their theoretical foundations and final output of a mental model, but vary slightly in how they explain where and when incoming perceptions are processed.

**Multimodal Model**

A third theory related loosely to multimedia instruction was reported in Engelkamp’s (1998) book *Memory for Actions* (Reed, 2006). Sensory information is still understood to be visual or auditory as in the CTML and ITPC theories. However, Engelkamp’s theory adds an enactment component such as a motor control, speaking, or writing operation by the participant based on the audio and visual information provided.
Engelkamp’s multimodal theory differs from the CTML and ITPC by incorporating actions from the learner into the design. This theory is based on empirical research conducted over several years by Engelkamp and others where participants listened to action phrases and then were asked to perform the action in the phrases (Reed, 2006). A participant may hear a phrase or see an action in pictorial representation and then performs the action either with props or pretends to have the prop and goes through the physical motions. An example might be written instructions accompanied by a sketch to shuffle a deck of cards. The strength of the multimodal theory revolves around this enactment, which was observed in multiple conditions. Participants were able to replicate the written or pictorial instructions with either real or imaginary objects (Engelkamp, 1998).

The advantage of this model occurs when the participant performs the action requiring a mental model to be created. The participant otherwise could not perform the action if they did not understand the command (Steffens, Buchner, & Wender, 2003). The limitations of this model are significant as students cannot be expected, or able to enact the vast majority of the instructional material presented in school. These limitations have left the Multimodal model to be used in only a small set of learning situations.
CHAPTER 3

METHODOLOGY

This research applied a General Linear Model with Repeated Measures Analysis of Covariance (RMANCOVA). For this research, time serves as the within-subjects factor while treatment group (i.e., static and signaling, dynamic and signaling, static without signaling, and dynamic without signaling) served as the between-subject independent variable. Using this design, the current research addressed three research questions: (a) how does motion in multimedia science instruction impact students’ learning; (b) how does signaling in multimedia science instruction impact students’ learning; and (c) while controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to learning from multimedia presentations?

Participants

The literature has called for additional studies in multimedia learning that target younger students. As a result, the research population was comprised of high school students ranging in age from 14 through 18 that were enrolled in a science course. The school is located in an urban setting in the Southwestern United States. This age group was targeted following Mayer and colleagues’ recommendations and discussion of limitations to their work (i.e., short presentations with college age students in laboratory environments; Mautone & Mayer, 2001; Mayer & Johnson, 2008). Students were recruited from conceptual physics, biology, and zoology courses from a high school. According to the most recent data, 44.9% of school’s students are on free or reduced cost lunch, 17.4% are designated as Limited English Proficiency, and 95% of students exhibit
proficiency in reading, 72% in writing, and 79% in mathematics by graduation (“School Districts Accountability Department,” 2011). The participants were not enrolled in any classes taught by or associated with the researcher. All students enrolled in these science classes were invited to participate with this research, however only those students who voluntarily completed both assent and informed consent forms were considered participants.

Based on a power analysis, a target of 100 participants was recruited to ensure sufficient power (Gay, Mills, & Airasian, 2006). Of the 107 students who volunteered and turned in all necessary forms five participants were absent on either the pretest or post-test days and their data were not included in this study. Additionally, two participants acted inappropriately (e.g. talking and not engaging with their animations) during the post-test conditions and their data were not used in this study. One student was called out of the computer lab before finishing the concept map test and this incomplete assessment was not used. The remaining 99 students, 49 male and 50 female, were present both days and had sufficient time to finish all assessments and view their animation as long as they wished. Thus, only their data were used in this research.

Participants were randomly assigned to one of four conditions using the following procedure. Moments before interacting with the animations in post-test conditions, students met outside a computer lab where they were assigned a random code that corresponded to a computer station; twenty one were assigned to the static non-signaling group, twenty five were assigned to static signaling group, twenty six were assigned to motion non-signaling group, and twenty seven were assigned to the motion signaling group.
Materials

The dependent measures in this study included a multiple-choice content test, a concept map task, and four questions rating the mental effort of learning from the animations. The independent variables were either animations containing motion or static images, and the addition or omission of signaling words at key points of the animation. The Vandenburg and Kuse Mental Rotation Test (MRT) was administered to determine the student’s spatial ability (Vandenberg & Kuse, 1978). The MRT scores were used as a covariate in this study.

The first dependent measure used was to assess recall of knowledge. This 14 item multiple-choice content measure was administered before and after treatment. The content for this test was based on the material in the presentations. Using the Kuder-Richardson reliability index for determining internal consistency of a test following the pilot study in March 2011, a 17-item version of this instrument was found to have a reliability of $KR20 = .601$. The assessment used in this research was modified following an analysis of the pilot assessment. After eliminating questions that duplicated measurements made by the Mental Rotations Test, and rewording some of the stems this 14 multiple-choice assessment $KR20 = .712$ indicating a fairly high reliability coefficient (Gay et al., 2006). Each multiple-choice question was graded dichotomously as correct or incorrect. Each question had one correct answer and four distracters, options were labeled, A through E. Each participant’s total sum score of correct answers was calculated and recorded. There were no time constraints placed on this or any assessment allowing participants as much time as they needed to read and answer each question at
their own pace. Examples of the first three questions from this test can be found in Table 1, the entire assessment is in Appendix D.

Table 1.

**Sample Questions From Multiple-choice Assessment**

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Which of the following creates the greatest force responsible for creating the tides on Earth?</td>
<td>A. The Earth’s spin on its axis combined with the atmospheric winds</td>
</tr>
<tr>
<td></td>
<td>B. The Sun’s gravitational forces</td>
</tr>
<tr>
<td></td>
<td>C. The Moon’s gravitational forces</td>
</tr>
<tr>
<td></td>
<td>D. Mar’s and Venus’s gravitational forces pulling in opposite directions</td>
</tr>
<tr>
<td></td>
<td>E. The gravitational forces of all the planets in the solar system working together</td>
</tr>
<tr>
<td>2. How long does the moon take to orbit once around the Earth?</td>
<td>A. Once a day</td>
</tr>
<tr>
<td></td>
<td>B. Once every seven days</td>
</tr>
<tr>
<td></td>
<td>C. Once every twenty-seven days</td>
</tr>
<tr>
<td></td>
<td>D. Once every 30 days</td>
</tr>
<tr>
<td></td>
<td>E. Once every 365 days</td>
</tr>
<tr>
<td>3. Which of the following statements best describes what happens when the earth, moon and sun are all aligned (in a straight line) with each other?</td>
<td>A. The gravitational forces of the sun and moon work together to create very large tides.</td>
</tr>
<tr>
<td></td>
<td>B. The gravitational forces of the sun and moon work against each other to create very small tides.</td>
</tr>
<tr>
<td></td>
<td>C. The phase of the moon is in what is called a first quarter moon</td>
</tr>
<tr>
<td></td>
<td>D. The phase of the moon is in what is called a second quarter moon</td>
</tr>
<tr>
<td></td>
<td>E. This phase of the moon is in what is called a third quarter moon</td>
</tr>
</tbody>
</table>

The second dependent measure used in this research was a concept map task related to tides. Concept map assessments were used because the construction of a map requires students understand and represent the relationship between and among concepts as well as synthesize their knowledge structure (Jacobs-Lawson & Hershey, 2002). Further, they are used extensively in science education to observe changes in student
knowledge over time (Ingec, 2009). Similarly, concept maps can assess the student’s understanding of science concepts (McClure, Sonak, & Suen, 1999) and their declarative knowledge and understanding of hierarchical ideas and the relationship between complex systems (Jacobs-Lawson & Hershy, 2002; Yin, 2008).

While concept maps often reflect a hierarchical structure forming to Ausubel’s (1968) Hierarchical Memory Theory, concept maps also may be constructed without this structure as explained by Deese’s (1965) Associationist Memory Theory (McClure et al., 1999). Considering the introductory nature of the science content in these animations a complex hierarchical structure was not anticipated and no weighted scoring was placed in the rubric used to assess the concept maps. Controlling for the consistency a concept map is evaluated by is an important factor when determining the reliability of a concept maps assessment value (McClure et al., 1999). The Associationist theory relates the concepts in the nodes in a similar cognitive structure as word associations or similarity judgments, and therefore may produce maps without labeled lines (Ruiz-Primo & Shavelson, 1996). This allows for an indirect assessment to elicit a cognitive structure from the nodes represented in the concept maps.

Based largely upon these principles, a rubric identifying key concepts within the nodes was constructed prior to the research project. The rubric was divided into two assessments: quantitative and qualitative. Quantitative measures used were: (a) total number of concepts, (b) total number of cross-links, (c) total number of levels, and (d) total number of concepts in each level. Qualitative measures identified the increase between pretest and post-test in five key concepts: (a) moon, (b) tides, (c) sun, (d) earth, and (e) astronomy. The development of the rubric and the quantitative and qualitative
measures were based on the research of Jacobs-Lawson and Hershey (2002) and guided by the recommendations for scoring concept maps by Ruiz-Primo and Shavelson (1996). The rubric is presented in Table 2. While it was impossible to anticipate all the words participants might use in the qualitative section, a short list of terms used in the animations was included in the rubric to help the two raters. Inter-rater reliability was determined using Coehn’s kappa statistic. The kappa statistic calculated for the reliability between the two raters for the pretest concept maps was .929 and .938 for the post-test concept maps indicating a high reliability (Viera et al., 2005). The sum scores for each category, qualitative and quantitative from the two raters were averaged to determine the composite scores used in each category for the RM ANCOVA analysis.
Table 2

*Concept Map Rubric*

<table>
<thead>
<tr>
<th></th>
<th>Quantitative</th>
<th>Pretest</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of concepts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of cross links</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of levels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of concepts in level 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of concepts in level 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of concepts in level 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of concepts in level 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater comments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Qualitative</th>
<th>Pretest</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon (full, half, fourth, new, monthly change, calendar)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tides (high, low, spring, neap, differences in size)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sun (distance, size)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earth (water, shoreline, bulge, ocean, animals, ecosystem)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astronomy (gravity, orbit, rotation, position in space)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rater comments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Qualitative totals</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

While many students are taught how to construct concept maps in school, the research procedure used in this study did not assume students would remember the design elements of a concept map. Additionally, we did not predict highly organized structure due to the introductory nature of the multimedia content, and the time constraints of using authentic classroom environments. Students may feel a sense of urgency to complete all the tasks in pre and post-test conditions. In order to decrease participant stress and cognitive demands during both pretest and post-test conditions, instructions on how to construct a concept map were read by the researcher, a written version of the instructions.
was provided, and a visual example was included. Concerted effort was made to keep this task simple yet concise. This helped ensure that participants’ responses would not be constrained while managing the limited available time to conduct the research (McClure et al., 1999). Finally, due to a wide variations concept maps can be produced and the anticipated inexperience these participants may have had, the three recommendations from Ruiz-Primo and Shavelson (1996) for concept map assessment were incorporated into this assessment (a) a clear task for the participants to engage in, (b) a format for their responses, and (c) an established scoring system was followed. A typical example of a student pre and post-test concept maps can be found in Figures 8 and 9 respectively.
Figure 8. Example Pretest Concept Map.
The third dependent measure used in this research measured the cognitive difficulty of learning from the animations. This assessment contained four questions inquiring about: (a) the difficulty of learning the material in the animations, (b) the difficulty understanding when and why the moon phases change, (c) the difficulty understanding when and why the largest and smallest tides occur, and (d) the difficulty understanding how much time there is between major moon phases. The students answered on a 9-point Likert-type scale based on the mental effort scale used by Paas (1992) with categories ranging from very, very difficult (1) to very, very easy (9). The
scale was explained during the post-test conditions. This subjective format is commonly used by researchers interested in measuring cognitive difficulty of participants engaged in multimedia content (see Haslam & Hamilton, 2010; Hasler et al., 2007; Paas, Tuovinen, Tabbers, & van Gerven, 2003; Paas & van Merrienboer, 1994; Paas, van Merrienboer, & Adam, 1994) and has been found to be reliable method (Ayres, 2006b). The four cognitive difficulty questions used in this research can be found in Appendix E.

The Vandenburg and Kuse Mental Rotations test (MRT) was used as a covariate to account for spatial ability differences. The MRT test is commonly used to measure spatial ability in multimedia research (see DeLeeuw & Mayer, 2008; Guillot, Champely, Batier, Thiriet, & Collet, 2007; Kühl et al., 2011; Stull et al., 2009). Spatial ability varies among individuals and is based on the ability to use nonlinguistic information that includes the transformation, recall, representation, and generation of symbolic information (Cherney & Neff, 2004). There is evidence from prior research that links a student’s ability to learn abstract science concepts to their spatial ability (Guillot et al., 2007; Jones et al., 2010; Stull et al., 2009). The MRT has a high reliability ($KR_{20} = .88$) and a test retest reliability of .83 (Vandenberg & Kuse, 1978). Given the spatial relationships of the Moon, Earth, and Sun in this study, understanding the visual information contained in the animations is essential. As a result, this test was used to control for the spatial ability variations among individuals. The MRT was given to all participants during pretest conditions.

The written instructions were provided and read clearly to all participants. There are three examples provided after the instructions for the students to practice before starting the test. The test contains two subtests, each with 10 target images; each target
contains ten blocks connected in a 3-dimensional representation with three right angle bends. Each target image has four similar images to the right of it. Two of the four images have been rotated 60°, 120°, or 180° and are the “goal” images and two images are “distracters” represented as mirror images to the target. Participants must identify the two rotated goal images as matches to the target as opposed to the two distracter mirror images. The test was scored according to Vandenberg and Kuse (1978) recommendations “to count each line (item) as correct if both choices are correct and to give no credit otherwise” (p. 599-600).

Procedure

Participants engaged with the multimedia science material on a Computer with a 17-inch monitor in a high school computer lab. The content of the presentations was introductory information describing the complex gravitational interactions between the Moon, Sun, and Earth and how these forces create the tides on earth. All participants were provided with stereo headphones that have a volume control so they only heard the presentation assigned to them. Participants had the ability to control (i.e., play, pause, or rewind) their animations. Within the constraints of the class period, participants were allowed as much time to view their presentation as needed. For each of the four treatment conditions (i.e., static with signaling, static without signaling, motion with signaling, and motion without signaling), three animations with different spatial perspectives were created to represent interactions among the Sun, Earth, and Moon. These varying viewpoints were a depth of field, side view, & polar view. An example of a signaled and non-signaled screen shot from each of the three view points can be found in Figures 2, 3,
4, 5, 6, and 7. Screen shots from the static signaled treatment can be found in Appendices A, B, and C.

The animations were embedded into a PowerPoint presentation that lasted approximately four minutes and 53 seconds. PowerPoint was used because students are already familiar with the software and this would help to limit potential extraneous load. The same CTML principles of modality, segmenting, temporal contiguity, and redundancy were applied when designing each of the three parts of the animations to either eliminate or significantly reduce cognitive load, confounding variables, and information non-equivalence. The modality principle was used by combining narration with pictorial information, the segmenting principle was incorporated by creating three short animations from three viewpoints and by allowing the participants to control the pace by stop, play, and rewind functions. The temporal contiguity principle was used by simultaneously showing the visual material as the narrations played, and the redundancy principle was not violated as all signaling cues were short one or two word captions presented near the part of the graphic they described instead of using onscreen captions containing the same words in the narration (Mayer, 2009).

Narration was embedded into the animations in an effort to reduce any influence of reading ability on performance and to create as much informational equivalence as possible. Information non-equivalence has been documented in research comparing static and dynamic animations (Tversky et al., 2002) and the methodological confounds inherent when comparing learning from two media such as written words on paper to narrations. Mayer (2009) pointed out that tone or voice inflections cannot be replicated with written text nor are pictorial mental representations and verbal mental
representations informationally equivalent so there is inherent difficulty trying to
determine if students are learning by the content or by the medium. Rather than have half
the participants engage in a paper treatment with static pictures and written words, and
half engage with a computer based dynamic animation containing narration it was
decided to imbed identical narration in all four treatments and have static images
presented on a computer screen instead of on paper.

The pretest conditions occurred one week before the treatment and post-test
conditions. The pretests and MRT were administered in a science classroom while the
post-tests and treatment were administered in a computer lab. Written and verbal
instructions were provided on all assessments and a simple visual example of a concept
map accompanied that particular assessment on both the pre and posttest.

The 14 question multiple-choice pre and post-test content knowledge assessments
were presented on 8 x 11 paper. Students answered on a standard optical answer sheet
and assessed as either correct or incorrect. Examples of the first three questions from this
test can be found in Table 1, the entire assessment is in Appendix D. Each question had
only one correct answer and the content from the questions was addressed in the
animations, narrations, or both.

A concept map was used to measure synthesis of knowledge and students’
understanding of the interactions associated with the science content. Participants had to
construct their own concept maps on separate 8 X 11 sheets of paper provided to them.
Participants were asked to construct a concept map in pretest conditions and than again a
week later after viewing the presentations.
Two raters assessed the concept maps. To assess changes in students’ knowledge from pretreatment to post-treatment the following four markers were counted quantitatively: (a) the number of concepts, (b) the number of hierarchical levels represented, (c) the number of concepts contained in a level, (d) and the number of cross links. This analysis is similar to the research methods used by Jacobs-Lawson and Hershey (2002) with one point assigned for each acceptable concept represented by the participant. Considering the multimedia presentation used for this lesson is introductory in nature, special weighting was not applied to any of the four categories identified. Qualitative analysis was conducted by identifying increases from pretest to post-test in five key concept areas: Moon, Tides, Sun, Earth, and Astronomy. To aid in reliability and validity of scoring a list of acceptable concepts were generated for concept map evaluation (Jacobs-Lawson & Hershey, 2002; McClure et al., 1999). Two raters using this list (see Table 2) had inter rater reliability determined by using Cohen’s Kappa statistic of .929 on the pretest and .938 for the post-test.

Finally, four questions were designed to measure the mental effort used by the student during the multimedia presentation. The explanation of the Likert scale was provided during the post-test conditions in the computer lab before the participants engaged with their animations. Participants completed this assessment after viewing their animation. The length of these questions and the nine-point Likert scale is modeled from a mental effort assessment used by Paas (1992) and can be found in Appendix E.
CHAPTER 4

RESULTS

This evidence-based research study with a True Experimental Design investigated the instructional advantages of using motion or static images while including or excluding signaling when using multimedia instruction in a high school classroom. Specifically, it addressed the following three research questions: (a) how does motion in multimedia science instruction impact students’ learning, (b) how does signaling in multimedia science instruction impact students’ learning, and (c) while controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to learning from multimedia presentations?

This research applied a General Linear Model with Repeated Measures Analysis of Covariance (RMANCOVA) to the data. This approach was selected because: (a) participants’ responses were measured at two periods of time (prior to the intervention and immediately following the intervention) and (b) multiple measures were administered on each occasion. For this analysis, time served as the within-subjects factor while treatment group (i.e., static and signaling, dynamic and signaling, static without signaling, and dynamic without signaling) served as the between-subject independent variable. Scores from the 14-item multiple-choice knowledge assessment and scores from the concept map evaluation were used as the dependent measures in this analysis while using scores from the Mental Rotations Test (MRT) as the covariate. The measures that were collected at post-test only were analyzed using a MANCOVA (i.e., mental effort).
Data Screening Techniques

Prior to performing the analyses for each of the research questions, the assumptions of each model were examined. With respect to outliers, Tabachnick and Fidell (1996) identify outliers as any extreme result on a variable that effectively distort the statistics. Statistically, cases with standardized scores in excess of 3.29 are potential outliers, though some are expected in studies with large populations. Although scantron methods were used for the content measure, all data were scanned visually for outliers.

With respect to normality, Tabachnick and Fidell also argue that if the skewness or kurtosis statistic has an absolute value greater than 2.00, then the distributions are considered non-normal. Similarly, Morgan and Griego (1998) report that if the skewness and/or kurtosis statistic is greater than 2.5 times the respective standard error, then the assumption of normality is not upheld. Only one variable violated the assumption of normality (i.e., crosslinks). Upon further analysis, the number of crosslinks did not yield meaningful results; most students did not relate concepts beyond simple methods and scored a zero for both pre and post maps. To enhance parsimony of the model and improve interpretability of the results, the crosslinks variable was not included in analyses.

Research Questions One and Two

The RM ANCOVA was applied to the data to evaluate questions one and two. The analysis indicated a main effect occurred and was appropriate for question one and two. Box’s $M$ test for the equality of covariance matrices was found to be significant [Box’s $M = 201.534, F (108, 18413) = 1.575, p < .001$]. Because the covariance matrices of the dependent variables may be significantly different, or heteroscedastic, from one another
for this category the results should be interpreted with caution. With the exception of equality of sample sizes, the remaining assumptions were upheld. Because it was not feasible to reduce the cell sizes, Pillai’s Trace statistic was used as a more conservative test for significance in the RM ANCOVA (Tabachnick & Fidell, 1996).

Results of the RM ANCOVA indicated statistical significance for the within subjects effect over time for all participants [Pillai’s Trace = .203, $F(4, 90) = 5.736, p < .001, \eta^2 = .203$]. The covariate, Vandenberg Kruse MRT was found to be significant, [Pillai’s Trace = .222, $F(4, 90) = 6.404, p < .001, \eta^2 = .222$]. The MRT mean score was 16.67 from a possible total of 40. Follow up univariate tests were used to examine within subjects differences. Analysis indicated that there was a significant effect with time and knowledge retention measured from the multiple-choice results [$F(1, 93) = 19.042, p < .001, \eta^2 = .170$]. Figure 10 represents these gains in the estimated marginal means for the knowledge test over time (i.e., pre-test to posttest).
There were no significant differences between groups for knowledge retention, however analysis of learning gains by group (static and motion), or by treatment (signaled or non-signaled) show mean scores increased from pretest to post-test in both comparisons. See Table 3 for the means, standard deviations, and standard error of the mean for the group comparisons, and Table 4 for the means, standard deviations, and standard error of the mean for the treatment comparisons. Results also indicated that the interaction of knowledge among groups over time was not significant.
Table 3

Groups Multiple-choice Assessment Data.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>4.61</td>
<td>1.99</td>
<td>.29</td>
</tr>
<tr>
<td>motion</td>
<td>4.49</td>
<td>2.25</td>
<td>.31</td>
</tr>
<tr>
<td>Post-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>static</td>
<td>7.17</td>
<td>3.40</td>
<td>.50</td>
</tr>
<tr>
<td>motion</td>
<td>7.08</td>
<td>2.88</td>
<td>.40</td>
</tr>
</tbody>
</table>

Table 4

Treatment Multiple-choice Assessment Data.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-signaling</td>
<td>4.81</td>
<td>2.34</td>
<td>.34</td>
</tr>
<tr>
<td>Signaling</td>
<td>4.31</td>
<td>1.91</td>
<td>.26</td>
</tr>
<tr>
<td>Post-test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-signaling</td>
<td>7.04</td>
<td>2.95</td>
<td>.43</td>
</tr>
<tr>
<td>Signaling</td>
<td>7.20</td>
<td>3.28</td>
<td>.46</td>
</tr>
</tbody>
</table>

Univariate follow up tests were also conducted on the concept map variables. These results indicated that the category quality of concepts represented in the concept map analysis was significant \( F(1,93) = 5.712, p = .019, \eta^2_p = .058 \). Figure 11 represents the change in marginal means for the quality of concepts for the concept map assessment over time (i.e., pre-test to posttest).
There were no significant gains for the category number of concepts represented in the concept map. There was no significant difference between treatment groups for any of the concept map variables. Results indicated that the interaction of concept map variables (number of concepts, levels, and quality of concepts) among groups over time was not significant. See Table 5 for the means, standard deviations, and standard error of the mean for the group comparisons, and Table 6 for the means, standard deviations and standard error of the mean for the treatment comparisons from the concept map analysis.
Table 5

*Groups Concept Maps Assessment Data*

<table>
<thead>
<tr>
<th>Number of Concepts</th>
<th>Groups</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>Static</td>
<td>4.76</td>
<td>3.62</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>Motion</td>
<td>4.98</td>
<td>3.58</td>
<td>.50</td>
</tr>
<tr>
<td>Number of Concepts</td>
<td>Static</td>
<td>6.02</td>
<td>3.96</td>
<td>.58</td>
</tr>
<tr>
<td>Post-test</td>
<td>Motion</td>
<td>5.58</td>
<td>2.46</td>
<td>.34</td>
</tr>
<tr>
<td>Number of Cross-links</td>
<td>Static</td>
<td>0.35</td>
<td>1.20</td>
<td>.18</td>
</tr>
<tr>
<td>Pretest</td>
<td>Motion</td>
<td>0.27</td>
<td>0.77</td>
<td>.11</td>
</tr>
<tr>
<td>Number of Cross-links</td>
<td>Static</td>
<td>0.07</td>
<td>0.33</td>
<td>.05</td>
</tr>
<tr>
<td>Post-test</td>
<td>Motion</td>
<td>0.25</td>
<td>0.62</td>
<td>.09</td>
</tr>
<tr>
<td>Number of Levels</td>
<td>Static</td>
<td>2.20</td>
<td>1.71</td>
<td>.25</td>
</tr>
<tr>
<td>Pretest</td>
<td>Motion</td>
<td>2.06</td>
<td>1.34</td>
<td>.19</td>
</tr>
<tr>
<td>Number of Levels</td>
<td>Static</td>
<td>2.46</td>
<td>1.53</td>
<td>.23</td>
</tr>
<tr>
<td>Post-test</td>
<td>Motion</td>
<td>2.33</td>
<td>0.94</td>
<td>.13</td>
</tr>
<tr>
<td>Quality of Concepts</td>
<td>Static</td>
<td>3.17</td>
<td>2.23</td>
<td>.33</td>
</tr>
<tr>
<td>Pretest</td>
<td>Motion</td>
<td>2.92</td>
<td>2.16</td>
<td>.30</td>
</tr>
<tr>
<td>Quality of Concepts</td>
<td>Static</td>
<td>4.70</td>
<td>2.81</td>
<td>.42</td>
</tr>
<tr>
<td>Post-test</td>
<td>Motion</td>
<td>4.35</td>
<td>2.19</td>
<td>.30</td>
</tr>
</tbody>
</table>
Table 6.

*Treatment Concept Maps Assessment Data*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error of the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Concepts Pretest</td>
<td>Non-signaling 5.13</td>
<td>3.86</td>
<td>.57</td>
</tr>
<tr>
<td></td>
<td>Signaling 4.65</td>
<td>3.34</td>
<td>.46</td>
</tr>
<tr>
<td>Number of Concepts Post-test</td>
<td>Non-signaling 5.60</td>
<td>3.02</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>Signaling 6.00</td>
<td>3.44</td>
<td>.48</td>
</tr>
<tr>
<td>Number of Cross-links Pretest</td>
<td>Non-signaling 0.15</td>
<td>0.52</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Signaling 0.44</td>
<td>1.26</td>
<td>.18</td>
</tr>
<tr>
<td>Number of Cross-links Post-test</td>
<td>Non-signaling 0.15</td>
<td>0.52</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Signaling 0.17</td>
<td>0.51</td>
<td>.07</td>
</tr>
<tr>
<td>Number of Levels Pretest</td>
<td>Non-signaling 2.15</td>
<td>1.60</td>
<td>.24</td>
</tr>
<tr>
<td></td>
<td>Signaling 2.10</td>
<td>1.46</td>
<td>.20</td>
</tr>
<tr>
<td>Number of Levels Post-test</td>
<td>Non-signaling 2.24</td>
<td>1.21</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Signaling 2.52</td>
<td>1.28</td>
<td>.18</td>
</tr>
<tr>
<td>Quality of Concepts Pretest</td>
<td>Non-signaling 3.07</td>
<td>1.91</td>
<td>.28</td>
</tr>
<tr>
<td></td>
<td>Signaling 3.02</td>
<td>2.42</td>
<td>.34</td>
</tr>
<tr>
<td>Quality of Concepts Post-test</td>
<td>Non-signaling 4.13</td>
<td>2.33</td>
<td>.34</td>
</tr>
<tr>
<td></td>
<td>Signaling 4.85</td>
<td>2.60</td>
<td>.36</td>
</tr>
</tbody>
</table>

One final analysis was done to determine if there was a significant three-way interaction among time, groups (static and motion), and treatment (signaled and non-signaled) in order to address questions one and two. Results did not indicate significance for any of the knowledge measures (i.e., knowledge, number of concepts, number of levels, or quality of concepts).

**Research Question Three**

To address question three, a MANCOVA was applied to the data from an assessment of cognitive difficulty associated with learning from the animations, which was administered after participants finished viewing their multimedia presentation. All four questions asked students to rate the difficulty of learning on a nine point Likert-type
scale. Specifically, the four multiple-choice questions were entered as dependent variables using grouping as the fixed factor. The mental rotations test served as the covariate. Multivariate assumptions were tested and upheld. An analysis of between group effects did not reveal a significant result. No further analysis was conducted. The mean scores, standard deviations and standard error statistics from the MANCOVA can be found in Table 7.
### Table 7.

**Mental Effort Descriptive Statistics.**

<table>
<thead>
<tr>
<th>Cognitive Difficulty Q15</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static-Non-Signaling</td>
<td>5.50</td>
<td>1.860</td>
<td>.365</td>
</tr>
<tr>
<td>Static-Signaling</td>
<td>5.30</td>
<td>1.750</td>
<td>.337</td>
</tr>
<tr>
<td>Dynamic-Non-Signaling</td>
<td>5.48</td>
<td>1.662</td>
<td>.363</td>
</tr>
<tr>
<td>Dynamic-Signaling</td>
<td>5.32</td>
<td>1.464</td>
<td>.293</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.39</td>
<td>1.671</td>
<td>.168</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cognitive Difficulty Q16</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static-Non-Signaling</td>
<td>5.46</td>
<td>1.860</td>
<td>.365</td>
</tr>
<tr>
<td>Static-Signaling</td>
<td>5.59</td>
<td>1.782</td>
<td>.343</td>
</tr>
<tr>
<td>Dynamic-Non-Signaling</td>
<td>6.10</td>
<td>1.729</td>
<td>.377</td>
</tr>
<tr>
<td>Dynamic-Signaling</td>
<td>5.24</td>
<td>1.422</td>
<td>.284</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.58</td>
<td>1.709</td>
<td>.172</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cognitive Difficulty Q17</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static-Non-Signaling</td>
<td>5.27</td>
<td>1.779</td>
<td>.349</td>
</tr>
<tr>
<td>Static-Signaling</td>
<td>5.15</td>
<td>2.013</td>
<td>.387</td>
</tr>
<tr>
<td>Dynamic-Non-Signaling</td>
<td>5.76</td>
<td>1.513</td>
<td>.330</td>
</tr>
<tr>
<td>Dynamic-Signaling</td>
<td>4.88</td>
<td>1.509</td>
<td>.302</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.24</td>
<td>1.733</td>
<td>.174</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cognitive Difficulty Q18</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static-Non-Signaling</td>
<td>5.73</td>
<td>2.146</td>
<td>.421</td>
</tr>
<tr>
<td>Static-Signaling</td>
<td>5.44</td>
<td>1.739</td>
<td>.335</td>
</tr>
<tr>
<td>Dynamic-Non-Signaling</td>
<td>6.67</td>
<td>1.494</td>
<td>.326</td>
</tr>
<tr>
<td>Dynamic-Signaling</td>
<td>5.88</td>
<td>1.616</td>
<td>.323</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.89</td>
<td>1.806</td>
<td>.182</td>
</tr>
</tbody>
</table>
CHAPTER 5
DISCUSSION

This research was designed to advance the empirical research in determining if younger students benefit from multimedia instruction similar to older college-aged participants frequently used in most of the current research. Mayer has called for research similar to this proposal in many of his research studies (Mautone & Mayer, 2001; Mayer et al., 2005; Mayer & Johnson, 2008). For this study, a True Experimental Design model was used to determine the cognitive benefits of using either motion or still images with signaling or without signaling in multimedia presentations. The goal was to increase student retention and synthesis of knowledge while learning about abstract science concepts.

To address the first two research questions: (a) how does motion in multimedia science instruction impact students’ learning, and (b) how does signaling in multimedia science instruction impact students’ learning, a General Linear Model: Repeated Measures RMANCOVA was used. This allowed for analysis for the effect of both group and treatment on the change of knowledge over time while holding the covariate constant. The independent variables were: static and signaling, dynamic and signaling, static without signaling, and dynamic without signaling. Scores from the 14-item multiple-choice content measure and the concept map were used as the dependent measures and the results of a Mental Rotations Test (MRT) served as the covariate. An additional MANCOVA analysis was conducted to address the third question: (3) while controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to
learning from multimedia presentations? The independent variables remained the same but the dependent variable used were four questions designed to measure mental effort.

**Question One**

The first question was tested based on a theoretical construct established in the static media hypothesis. According to the static media hypothesis static images and printed text are less cognitively demanding and can lead to deeper learning than dynamic animations containing narrations (Mayer et al., 2005). The continual change from frame to frame in a dynamic animation creates a situation that places more cognitive demands within the extraneous load of the learner compared to a similar situation where the images are static (Mayer et al., 2005). While the results indicated there was no significant differences between groups (static and dynamic) for knowledge gain, the analysis of within subjects effects from the 14 multiple-choice question assessment and concept map assessment shows significant gains were observed for all participants. This increase in knowledge retention is represented in figure 12 as the increase of mean scores by group (static and dynamic) from the multiple-choice test, and synthesis of knowledge in figure 13 as the increase of mean scores of quality concepts represented by group (static and dynamic) from the concept map.
Although there was an overall gain, there were no differences between groups as implied by the static media hypothesis. There may be several reasons why this research
was unable to demonstrate significance. First, this research chose to use computer-based multimedia presentations in all four treatments rather than comparing paper-based static images to computer-based animated presentations. This was done to minimize informational nonequivalence (see Mayer et al., 2005) as it is difficult, if not improbable, to design narrated animations that represent true informational equivalence to annotated illustrations. Narrations may contain changes in pitch and inflection that written text cannot provide. Further, one would have to include a static image from each animated frame for the static images to contain the same amount of information as a dynamic presentation. With respect to these challenges, Mayer et al. (2005) suggested, “future research is needed to disentangle which features of the paper and computer treatments contribute to differences in test performance” (p. 264).

Although this research is not conclusive, it may be a step in disentangling the influential cognitive factors Mayer is referring to. The results from this research indicate that when all participants are provided narrations, rather than half reading a transcript of the narration and half listening to the narration, differences in knowledge retention and synthesis of knowledge are minimized to a point where significant differences between groups was not detected. Providing narrations for all participants eliminated the cognitive differences of reading a transcribed narration compared to listening to the narration. This research comparing static and dynamic animations demonstrates that by eliminating the information nonequivalence between written text and narrated words can influence the learning outcomes in such a way that significant differences are minimized. Utilizing the auditory channel with narrations provides an educational equivalent experience where significant differences were not seen between static and dynamic animations.
This research also incorporated narration in all treatments in an effort to maximize generalizability by minimizing any effects due to varying reading abilities among participants. Previous research was conducted using participants that were enrolled in college and may have higher reading abilities and comprehension when compared to the younger population used here (Boucheix & Schneider, 2009; Lewalter, 2003; Mayer et al., 2005). Mayer et al. (2005) remarked, “it should be noted that the studies reported in this article are based on a highly selected population (i.e., college students at a selective university), so the results might not generalize to a population that includes lower ability or literacy individuals” (p. 264). Further, research with adult, skilled, native English speaking participants should not be assumed to generalize across populations that contain younger, less skilled, non-native English speakers (McTigue, 2009). However, making suitable instructional modifications to the animations (i.e., adding narration and mitigating reading demands) may have also altered the cognitive demands associated with the material. Reading comprehension is a multi step process involving phonological awareness, knowledge of the semantics and syntax of the words, and making meaning of terms in the context of a sentence and paragraph, (Mayer, 1998). Ultimately, this change may have minimized the effects theorized in the static-media hypothesis, suggesting that variations in reading ability and reading comprehension may have had a larger influence than the cognitive demands required to learn from a continuously changing dynamic animation.

Additionally, constraints with classroom time and concerns of cognitive fatigue prevented the administration of a reading comprehension test in addition to the spatial ability MRT to serve as a second covariate. Finally, other mitigating circumstances that
by themselves or in some synergistic way minimized an effect across groups and
treatment are: (1) this research used three short animations from three different viewer
perspectives; depth of field, side view, and polar view instead of the more common
animation design containing a single point of view, (2) the animations were four minutes
and 53 seconds in duration and some visual and verbal content is repeated, (3)
participants had as much time as they needed to view their presentation and, (4)
participants had full interactive access to pause, rewind, or even stop their animation. The
duration of the animations, the three varying perspectives, and ability to interact with the
media as needed may have compensated for the cognitive differences predicted from the
static-media hypothesis.

In summary, design decisions based on suggestions from previous research in
static and dynamic media research and instructional design features aimed at lowering
cognitive load may have all or in part contributed to finding no significant differences
between groups. Using pre-college aged participants led to a decision in the instructional
design to minimize the potential confounding variable of reading ability. The effort to
minimize an effect of information nonequivalence by using narration with all treatments,
and the design features of providing varying view points, operational control, and longer
animations containing repeated content may all played a role equalizing cognitive load
for all participants. Regardless of our ability to confirm the static media hypothesis, this
research does indicate that both static and dynamic animations have positive effects on
learning.
Question Two

The second question was tested based on a theoretical construct established in the cognitive theory of multimedia learning (CTML). According to the CTML meaningful learning occurs as the participant selects, organizes and then integrates the information with their prior knowledge (Kalyuga, 2011; Mayer, 2005, 2009). Each of these three processes requires cognitive effort and depending upon the intrinsic and extraneous loads of the multimedia material an active learner may encounter cognitive processing overload. According to the knowledge construction hypothesis adding signaled cues may guide learners to the most relevant material and lower the cognitive demands placed on the learner (Mautone & Mayer, 2001). The treatment groups receiving signal cues in theory should have an essential processing advantage over the non-signaled groups and increased learner outcomes should be identified. The analysis of within subjects effects from the 14 multiple-choice question assessment and concept map assessment showed no significant differences could be measured between signaled and non-signaled groups, instead participants showed significant gains in knowledge and quality of concepts represented regardless of treatment. The significant gains in knowledge retention are represented in figure 14 as the increase of mean scores by treatment (signaled and non-signaled) from the multiple-choice test, and synthesis of knowledge in figure 15 as the increase of mean scores of quality concepts represented by treatment (signaled and non-signaled) from the concept map assessment.
The signaling cues used in this research were designed to be simple two word cues that appeared during corresponding visual events in the animations. The cues used
were “full moon”, “half moon”, “new moon”, and “tidal effect”. These signaling cues and the static images were placed to coincide with the narrated material. Possible explanations for why this experiment did not find significant differences between treatment groups might be attributed to either: (1) a weak treatment (i.e., the signaled words were too simple or perhaps even obvious and thus did not direct attention to salient details), (2) the participants did not notice the signals, and (3) the animations may have been designed in a manner that already lowered the cognitive demands (i.e., the animations represented introductory content from three perspectives, and they contained an interactive ability to stop, pause, or rewind if needed by the participant). Since the multimedia design used here adhered to the principles of modality, redundancy, segmenting, and temporal contiguity the cognitive load may have already been below a threshold that by adding the principle of signaling had little additional impact. Simply put, the extraneous load may already have been low enough for germane processing to organize and integrate the selected incoming information due to the design considerations previously mentioned. Alternatively, these signaling cues may not have lowered the cognitive demands enough to free up space for germane load to process the incoming information and integrate it with existing knowledge. Either way we found no significant differences between the signaled and non-signaled treatments, but we did find increased learner outcomes regardless of group or treatment.

**Question Three**

The last question pursued in this research, while controlling for spatial ability, does the incorporation of signaling in animations using either motion or static images alter the cognitive load in working memory with respect to learning from multimedia.
presentations, is founded on a fundamental assertion in the cognitive load theory.

Described earlier, working memory capacity in the brain varies among individuals but appears to be controlled by three different forms of cognitive load demands: intrinsic, extraneous, and germane loads (Chandler, 2004; Chandler & Sweller, 1991; Höfllcr & Leutner, 2007; Sweller, 1994). The intrinsic load is determined by the complexity of the material presented while the extraneous load is determined by how the material is presented. If the intrinsic and extraneous loads are both high than the limited capacity within the working memory may be over loaded and thus limit germane processing.

The MANCOVA conducted on the mental effort questions determined there were no significant differences between the groups in any of the four questions. Question one asked participants to rate how difficult it was to learn the material from the presentation they just watched, the second question asked how difficult it was to understand the explanation of when and how the moon phases change, the third question asked how difficult it was to understand the explanation of when and how the largest and smallest tides occur, and the fourth question asked how difficult it was to understand the explanation of how much time there is between major moon phases. These questions were designed to get a comprehensive view of the cognitive load experienced by the participants in the overall experience as referenced in question one, but also in understanding important scientific concepts important to this lesson such as moon phase changes, variations in tides, and time elapsed between moon phases. Considering the results of the four questions showed no significant variations of cognitive effort was encountered by the participants, one could conclude that either the inclusion or exclusion
of signaling with static or dynamic animations had no significant effect on minimizing or increasing the extraneous cognitive load.

Explanations to why no significance was detected may include: (1) the participants did not understand the nine point Likert scale used in the assessment, or (2) the participants believed the content presented was not difficult as the average mean scores indicate. The average mean scores for questions one, two, three, and four were 5.39, 5.58, 5.24, and 5.89 respectively. This corresponds to the rating of 5 on the Likert scale “average for school presentations”, or if rounding up to 6 “slightly easy”. Considering measuring cognitive difficulty with this type of subjective format is common and determined to be reliable, not finding significant differences indicates the multimedia presentation these participants engaged with were appropriate for their educational level. By not having one group or treatment experiencing significantly higher or lower cognitive demands all participants could succeed in learning which is the ultimate goal of any teacher.

Conclusions

The results of the MANCOVA from the mental effort questions could be interpreted to imply that the multimedia presentations, regardless of group or treatment, were not cognitively demanding in terms of either intrinsic or extraneous load. This would explain why no significant differences were identified and why this research did not appear to support the static-media hypothesis or the knowledge-construction hypothesis. If the participants reported that they were not being cognitively challenged, then the type of animation (i.e., static or dynamic) would not play a significant factor in the amount of germane processing available to integrate the material into prior
knowledge. Similarly, the instructional media would not have a significant effect concerning the inclusion or exclusion of signaling cues. This would leave individual differences (e.g., attentiveness, time on task, prior knowledge, and degree of engagement) as well as the impact of incorporating the principles of modality, redundancy, segmenting, and temporal contiguity, to have larger influences on the cognitive demands in working memory.

The increase in mean scores from pretest to post-test conditions (i.e., knowledge and quality of concepts) demonstrate multimedia instruction can increase student understanding, retention, and synthesis of knowledge when teaching pre-college participants in classroom settings with which they are familiar. These results may be an indication that eliminating information nonequivalence, and confounding variables where possible, is more significant improving learner outcomes than focusing on a single design principle. Additionally, generalizing results from research on college students, where designed animations on technical topics (i.e., flushing toilets, car brakes, lightning formation, and lift created by an airplane wing) are used in laboratory settings, may not apply to high school students learning introductory material in their own school settings.

**Instructional Implications**

The results from this study have implications for the CTML and may provide valuable information for instructional designers and teachers. Those that intend to supplement instruction with multimedia animations in high school science courses may want to focus on the quantity and quality of the design principles that go into the presentation more than the static or dynamic nature of the animation. More important decisions may come from other factors (i.e., time on task, prior knowledge, degree of
student interactivity with the media, incorporating the principles of modality, redundancy, segmenting, spatial contiguity, and temporal contiguity) that can limit, or lower the cognitive demands within working memory.

Additionally, applying the CTML principles would be beneficial when teaching abstract science concepts. Abstract topics can include concepts that involve movement and objects either too large to be seen in connection with other related objects or too small to be seen (Jones et al., 2010). Some examples of abstract subjects within science courses include: chemical bonding, structure of an atom, astronomical concepts, mountain building, or lessons with electronic circuits. Science and math curricula contain an abundance of abstract subject material in which multimedia animations could enhance knowledge construction as well as synthesize and build a coherent structure to the knowledge.

Instruction in contemporary classrooms relies on multiple resources to convey subject matter to students. Traditional textbooks, lecture, hands on activities, and multimedia instruction are some of the more common practices. This research indicates the use of sound multimedia design, based on the affordances of the visual and auditory channels can help facilitate learning in the classroom.

Limitations of Study

The results of this research relate only to populations that are similar to those described here. Specifically, the inferences derived from this experiment would only be applicable to the high school students taking similar science courses. Further, the animations were created expressly to convey academic content contained within the curriculum guides of the classes the participants were recruited from. In many cases,
teachers find animations online or prepackaged in DVD format and do not have control over the content, or the CTML principles used with this research.

**Suggestions for Further Research**

More research is needed to determine whether or not the effects from the CTML can be generalized to a pre-college population. Results from this research would suggest future researchers interested in the multimedia effects on pre-college aged participants design multimedia content on a topic that is not an introductory topic. The animations and narrations used here were not cognitively demanding as indicated by the mental effort scores and thus finding variations from motion or signaling may not have been noticeable. A topic with higher intrinsic load may be able to tease out essential processing differences not observed here. Perhaps topics on genetic mutations, osmotic effects in cells, or flight adaptations in birds may provide a visually abstract content more appropriate.

Additionally, future studies may want to investigate the numerous ways classroom research differs from laboratory research, particularly with respect to multimedia learning theory. The research presented here incorporated instructional practices that are common among teachers in K-12 settings (i.e., repetition of key concepts and providing necessary time). Specifically, the scientific concepts of changing moon phases and time elapsing between these changes was repeated in two of the three animations. Further, information on the tidal effects on earth and when the largest and smallest tidal effects occur was also repeated. Classroom teachers often repeat information and provide adequate time for students to engage with their learning materials and assessments.
However, these instructional practices inherent to the traditional K-12 classroom may differ significantly from the practices used in college instruction or, more specifically, in a laboratory research setting. Both Reiber (2005) and McTigue (2009) warn practitioners that generalizing the findings from research conducted with older participants in a college lab setting to traditional K-12 learning environments is tenuous. With respect to the CTML principle of signaling with static or dynamic animations, these results indicate: (1) additional research is necessary to understand K-12 populations and (2) generalizing from one population to another, and from a college lab setting to a classroom setting may not be appropriate.

Finally, if future research were to be conducted within the confines of an authentic classroom with the time constraints inherent in a middle or high school environment, pre-training in concept map construction for participants would be advised. The concept maps produced from the participants in this research were limited in their overall structure. Specifically, the number of levels and the number of crosslinks did not change meaningfully. Further, there were reasons to doubt the value of the crosslinks variable (i.e., normality, range, etc.). If pre-training, or additional class time for the research is not possible than a longer multiple-choice assessment with a high KR20 value may be warranted. Students are used to taking multiple-choice assessments and may feel less stressed to finish multiple activities with limited time constraints.

**Concluding Remarks**

From an instructional standpoint with an introductory lesson finding consistent success across all participants is significant. With increased access to technology (e.g., e-tablets, internet access, computers in classrooms, and streaming educational content), the
importance of establishing instructional materials from evidence-based research is imperative. The multimedia principles established in the CTML by Mayer and his colleagues have laid an important foundation for future evidence-based research that needs to extend to participants in the K-12 setting. Determining what works best for this important population and subsequently getting those instructional practices to the teachers and instructional designers should continue to be a priority in Educational Psychology research.
In the first presentation we are looking at the sun in the upper left corner, the earth is spinning on its axis and coming towards you, and the moon is moving towards the earth as it completes one complete orbit. Duration 13 seconds. Key frame 01

If you visualized yourself on earth looking up at the moon you would see it go through four distinct phases. The moon reflects light from the sun so depending upon where the moon is positioned in relationship to the earth and sun you see different phases. Duration 16 seconds. Key frame 500
We see a full moon when the earth is positioned between the moon and the sun and the side of the moon facing the sun reflects light across its entire surface. Duration 11 seconds. Key frame 1000

In a 27 day cycle the moon will go from a half moon phase to a full moon, to a second half moon phase, to a new moon phase, and return back to where it started in a half moon phase. Duration 14 seconds. Key frame 1500
The half moon phases occur when the moon is positioned 90 degrees off to one side or the other from the earth. In these cases we can only see half of the moon's surface reflecting sunlight. Duration 13 seconds. Key frame 2000

The last phase we want to point out is the new moon phase. New moons occur when the moon is positioned between the earth and the sun. Duration 10 seconds. Key frame 2500
The side of the moon facing the sun is lit up, but the side facing the earth receives no sunlight. Because no light is reflected towards earth we can't see the moon in the sky during this phase. Duration 13 seconds. Key frame 3000

The position of the moon and sun is critical for determining where earth will experience the largest tides, called spring tides, and when the smallest tides will occur, called neap tides. Duration 13 seconds. Key frame 3500
When the moon and the sun are lined together with their gravitational forces they magnify the effects and we experience the largest tides. However, when the moon and sun are offset as in half moon phase their gravitational forces pull in different directions minimizing the effects. Duration 18 seconds. Key frame 3950
In this second presentation we only see the earth and moon as the moon orbits around the earth. We are focusing on the moon because it is so much closer to the earth than the sun and thus has a larger influence when it comes to creating tides. Duration 15 seconds. Key frame 01

As the moon orbits around the earth and the earth spins on its axis we experience daily tidal effects and monthly tidal effects. Today's presentation only focuses on the monthly effects. Duration 13 seconds. Key frame 120
These tidal effects can best be seen along the shorelines where the oceans come in contact with the continents. Duration 08 seconds. Key frame 237

The gravitational pull of the moon on the water creates a bulge that can be seen in our large oceans, but it is not strong enough to create an effect that can be seen on the continental rock. Duration 12 seconds. Key frame 389
In this second presentation the tidal effect is greatly exaggerated to get the point across. The tidal effect actually varies across the earth in different locations. Duration 12 seconds. Key frame 500

In most places the tidal effects along the shorelines brings ocean water on shore only a few feet, but in some unique locations like the Bay of Fundi in Canada, the highest tides bring ocean water up 55 feet on to the shorelines. Duration 15 seconds. Key frame 643
These tidal variations are important to marine biologists and sailors. Many of the aquatic animals have to adapt to these variations if they live near the shoreline. Duration 11 seconds. Key frame 739

Some animals like corals and sea turtles use the changes of tides to time their reproductive cycles. We will explore these details once we learn how tides are formed and how scientists can predict when they will occur. Duration 14 seconds. Key frame 904
In review, the tides are created mostly by the moon's gravitational pull and can be seen best along the oceans shorelines. Duration 09 seconds. Key frame 1026
In this final presentation we will see how scientists and sailors can predict when the largest and smallest of tides occur on earth. Duration 09 seconds. Key frame 01

This final presentation shows the earth make one complete trip, or orbit around the sun as the moon also orbits around the earth. Duration 09 seconds. Key frame 366
This last presentation should give you the full picture of how the position of the earth and moon change from one month to the next, but also how these changes are repeated each month. Duration 11 seconds. Key frame 800

In this last animation the white part of the moon is the side reflecting sunlight and can be seen from earth while the gray side receives no sunlight and would not be visible from earth. Duration 13 seconds. Key frame 1197
If you tried to visualize yourself on earth looking up at the moon as the earth orbited around the sun you could see the moon phases change four times each month. Duration 11 seconds. Key frame 1630

Because the Earth's orbit around the sun is very predictable and steady and the moon's orbit around the earth is also steady and predictable we can predict these tidal changes. Duration 12 seconds. Key frame 1928
We know how much time there is between each phase. It takes the moon seven days to move from a new moon phase to a half moon phase. Duration 09 seconds. Key frame 2200

In a half moon phase the sun, earth, and moon are not in line with each other so the moon's and sun's gravitational forces are not magnified. Duration 11 seconds. Key frame 2600
In another seven days the moon will move to the full moon phase and the sun, earth, and moon are in line with one another. It is here where we see one of the two largest tidal effects of the month. Duration 13 seconds. Key frame 3000

Seven days later the moon's position has changed and the gravitational forces from the moon and sun are working against each other. Duration 09 seconds. Key frame 3400
And finally, seven days later the moon is positioned between the earth and sun and the gravitational forces create the largest tides of the month. Duration 09 seconds. Key frame 3800

This last presentation showed an entire year of the earth's orbit. During each of the 12 months the moon would go through four separate phases so in one years time the earth will experience at least 24 spring tides and 24 neap tides. Duration 18 seconds. Key frame 4100
APPENDIX D: CONTENT KNOWLEDGE ASSESSMENT

Below you will find 14 questions for your teacher to get a better understanding of what you already know about some astronomy topics concerning the Sun, Earth and Moon and how well you can interpret diagrams. Please take your time and read each question carefully and then pick the best answer for each question. There is only one correct answer for each question.

1. Which of the following creates the greatest force responsible for creating the tides on Earth?
   A. The Earth’s spin on its axis combined with the atmospheric winds
   B. The Sun’s gravitational forces
   C. The Moon’s gravitational forces
   D. Mars and Venus’s gravitational forces pulling in opposite directions
   E. The gravitational forces of all the planets in the solar system working together

2. How long does the moon take to orbit once around the Earth?
   A. Once a day
   B. Once every seven days
   C. Once every twenty-seven days
   D. Once every 30 days
   E. Once every 365 days

3. Which of the following statements best describes what happens when the Earth, moon and sun are all aligned (in a straight line) with each other?
   A. The gravitational forces of the sun and moon work together to create very large tides.
   B. The gravitational forces of the sun and moon work against each other to create very small tides.
   C. The phase of the moon is in what is called a first quarter moon
   D. The phase of the moon is in what is called a second quarter moon
   E. This phase of the moon is in what is called a third quarter moon

4. Which of the following statements best describes tidal effects in the ocean?
   A. Tides occur equally in the Atlantic, Pacific, and Indian oceans.
   B. Tidal effects are best observed along the ocean floor
   C. Tidal effects are best observed near the equator
   D. Tidal effects are best observed on the ocean surface far from shore
   E. Tidal effects are best observed along the shoreline

5. Under what condition does a full moon occur?
   A. A full moon occurs when the Earth is located between the moon and sun
   B. A full moon occurs when the moon is located between the Earth and sun
   C. A full moon occurs when the Earth and moon are located on opposite sides of the sun
   D. A full moon occurs at the beginning of each month
   E. A full moon occurs at the beginning of a new season (spring, summer, fall & winter)
6. Which of the following statements best describes the ability to predict tides?
   A. The largest tides occur when the seasons change on Earth
   B. The smallest tides on Earth occur when solar and lunar eclipses occur
   C. The largest tides occur on Earth when there is a quarter moon
   D. The largest tides occur on Earth when there is a full or new moon
   E. The tides vary during the year depending upon which planets are near the Earth and which planets are farther away

7. How much time is there between the full moon and a new moon phases?
   A. 1 night
   B. 7 nights
   C. 14 nights
   D. 30 nights
   E. 365 nights

8. Which of the following statements best describes the conditions when there is a “new moon” phase?
   A. The “new moon” phase occurs four times a year as the seasons change from summer, to fall, to winter, to spring, and then back to summer
   B. The “new moon” phase occurs once a year as the Earth completes the yearly orbit around the sun
   C. The “new moon” phase occurs when another planet orbits in between the moon and sun and blocks the sunlight from reflecting off the moon
   D. The “new moon” phase occurs at the end of each month
   E. The “new moon” phase occurs once a month as the moon’s orbit brings the moon in between the Earth and sun and no sunlight is able to reflect back to Earth

9. Which of the following is an accurate statement about the moon’s orbit?
   A. The moon and sun are of equal distance from each other and that is why the orbit of the moon is equal in time from one month to the next
   B. The moon’s orbit is fixed around the Earth and does not vary and this is why changes in the phases of the moon can be easily predicted
   C. The moon is much further away from the Earth then the sun and that is why the orbit and phases of the moon vary so much each month
   D. The moon and sun’s orbit around the Earth are constant and this is why the phases of the moon remain constant
   E. The moon’s orbit matches the seasonal changes on Earth so we see a full moon each time we change from one season to the next.
10. Which of the following statements is most accurate concerning tides?
   A. Tides affect land to the same degree they effect the oceans
   B. Tides occur regularly on Earth and aquatic animals have had to adapt to these changes
   C. Tides occur equally on the Earth and moon as each have a gravitational pull on the other
   D. Tides vary on Earth depending upon the season (spring, summer, fall & winter)
   E. Tides occur regularly at the beginning of each month

11. Which of the following statements is most accurate concerning the amount of distance between the Earth, Moon and Sun?
   A. The sun and moon are equal distance from the Earth and are of equal size to each other
   B. The sun is more than 10 times farther away from the Earth then the moon and is over 100 times larger than the moon
   C. The moon is more than 10 times farther away from the Earth than the sun and is significantly smaller than the sun
   D. The sun is closer to the Earth in the summer but farther away in the winter, but the moon is always the same distance away from the Earth
   E. The sun and moon are equal distance from the Earth but the sun is twice as large as the moon is

12. Which of the following statements is the most accurate concerning ecosystems?
   A. Objects in our solar system like other planets, the moon, and sun can have direct influence and shape some of the ecosystems on Earth
   B. Objects in our solar system like other planets, the moon, and sun have little direct influence and cannot shape some of the ecosystems on Earth
   C. The sun is the only object in our solar system close enough to Earth that can directly influence and shape some of the ecosystems on Earth
   D. Only the sun and moon are close enough to have any direct influence and ability to effect ecosystems on Earth
   E. The moon and planets are the only objects in our solar system close enough to directly influence and shape some of the ecosystems on Earth
13. Which of the following statements is most accurate concerning the **Diagram** above?
   A. The moon is in the full moon phase and this is creating the largest tides on Earth
   B. The Moon is in the half moon phase and this is creating the largest tides on Earth
   C. The Moon is in the new moon phase and this is creating the smallest tides on Earth
   D. The Earth is entering the summer season, which will create the largest tides on Earth
   E. The Earth is entering the winter season, which will create the largest tides on Earth

14. Which of the following statements can be inferred based the **Diagram** above?
   A. Everyone on earth looking up at the moon at night during the stage this diagram represents would see a half moon
   B. Everyone on earth looking up at the moon at night during the stage this diagram represents would see a full moon
   C. Everyone on earth looking up at the moon at night during the stage this diagram represents would see a new moon
   D. Only people living in the western hemisphere that looked up at the moon at night during the stage this diagram represents would see a half moon
   E. Only people living in the southern hemisphere that looked up at the moon at night during the stage this diagram represents would see a full moon
APPENDIX E: FOUR COGNITIVE DIFFICULTY QUESTIONS

1. How difficult was it to learn the material in the 3 part presentation you just watched?

1- very, very difficult 2- very difficult 3- difficult 4- slightly difficult 5- average for school presentations 6- slightly easy 7- easy 8- very easy 9- very, very easy

2. How would you rate the quality of the presentation that you just saw? Specifically, how difficult was it to understand the explanation of when and how the moon phases change?

1- very, very difficult 2- very difficult 3- difficult 4- slightly difficult 5- average for school presentations 6- slightly easy 7- easy 8- very easy 9- very, very easy

3. How would you rate the quality of the presentation that you just saw? Specifically, how difficult was it to understand the explanation of when and how the largest and smallest tides occur?

1- very, very difficult 2- very difficult 3- difficult 4- slightly difficult 5- average for school presentations 6- slightly easy 7- easy 8- very easy 9- very, very easy

4. How would you rate the quality of the presentation that you just saw? Specifically, how difficult was it to understand the explanation of how much time there is between major moon phases?

1- very, very difficult 2- very difficult 3- difficult 4- slightly difficult 5- average for school presentations 6- slightly easy 7- easy 8- very easy 9- very, very easy
APPENDIX F: IRB APPROVAL

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

Social/Behavioral IRB – Exempt Review
Deemed Exempt

DATE: February 9th, 2011

TO: Dr. P.G. Schrader, Educational Psychology

FROM: Office of Research Integrity – Human Subjects

RE: Notification of review by Ms. Cindy Lee-Tataseo, BS, CIP, CIM
Protocol Title: How the Degree of Abstraction in High School Science Animations Relates to Cognitive Load and Learning
Protocol # 1007-3510M

This memorandum is notification that the project referenced above has been reviewed as indicated in Federal regulatory statutes 45CFR46 and deemed exempt under 45 CFR 46.101(b)1.

PLEASE NOTE:
Upon Approval, the research team is responsible for conducting the research as stated in the exempt application reviewed by the ORI – HS and/or the IRB which shall include using the most recently submitted Informed Consent/Assent Forms (Information Sheet) and recruitment materials. The official versions of these forms are indicated by footer which contains the date exempted.

Any changes to the application may cause this project to require a different level of IRB review. Should any changes need to be made, please submit a Modification Form. When the above-referenced project has been completed, please submit a Continuing Review/Progress Completion report to notify ORI – HS of its closure.

If you have questions or require any assistance, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 895-2794.
REFERENCES


VITA

Degrees:
University of Nevada Las Vegas, 2013
Doctor of Philosophy in Learning and Technology

University of Nevada Las Vegas, 1996
Masters of Arts in Science

University of Minnesota Duluth, 1991
Bachelors of Applied Science

Professional Experience
High School Science Instructor Clark County School District (1993-2013)

Middle School Science Instructor Morristown, Minnesota (1992-1993)


Presentations
Presenter for Curriculum & Professional Development (April 29th 2008)
Clark County School District

Instructor for Science Olympiad Coaches (January 2006)

Conducted Field tours for National Science Teachers Association (May 1998)

Publications

Honors, Awards, & Memberships
Distinguished Educator Award, Clark County School District (May 2009)

Grant Recipient from Junior League of Las Vegas (2008-2009)
“Recycled Technology Providing New Opportunities”

Outstanding Coach Award, Nevada State Science Olympiad (February 2005) Competition