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Does Multimedia Theory Apply to all Students? The Impact of Multimedia Presentations on Science Learning

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ABSTRACT

In K-12 school settings in the United States, 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 theory of multimedia learning (CTML) outlines numerous principles associated with learning from and with multimedia (Mayer, Hegarty, Mayer, & Cambell, 2005). However, the bulk of the research like the CTML has been conducted using college age students (Jones, 2010; McTigue, 2009). There is ample evidence that college age students and younger students exhibit numerous and important differences when learning from multimedia content (Hannus & Hyona, 1999; McTique, 2009; Moreno, 2007; Van Parreren, 1983). As a result, the objective of the current study is to examine the influence of multimedia presentations that leverage motion (present or absent) in conjunction with signaling cues (present or absent) on high school students' ability to learn science concepts. Using a 2x2 experimental design, 99 high school participants were randomly assigned to one of four conditions. Results of indicated statistical significance all participants over time for a *knowledge measure* and *quality of concepts* from a concept mapping task. Implications for multimedia learning theory on younger students are examined.

Keywords: *cognitive theory, multimedia, science, high school, learning*

INTRODUCTION

There is little doubt that the educational climate in the United States has changed dramatically over the last several years. There has been a profound shift toward standards-based education within the last decade alone. Similarly, there has been a rise in the availability and use of technology in classrooms, both on the part of the students and teachers (Purcell, Heaps, Buchanan, & Friedrich, 2013). Resources like games and smart devices continue to make headlines due to their increased use (Lenhart et al., 2008) and tools like blogs, wikis, and multimedia have become commonplace in classrooms (Bulter, Marsh, Slavinsky, & Baraniuk, 2014; Reiser, 2001a; 2001b).

Overall, the use of educational technology is both ubiquitous and diverse. Seemingly, there is no limit to the variety of resources available to teachers, all of which require time and resources to implement judiciously. Unfortunately, there also exists a tension between technology integration and educational pressures (e.g., standards-based instruction and professional accountability). As a result, teachers tend to question the benefits of spending time learning new tools when the instructional benefits are either unclear or limited (Bauer & Kenton, 2005; Cuban, 2001; Miranda & Russel, 2012). Teachers constantly appraise this curricular cost; there is little wonder that they may find themselves overwhelmed by the variety of technological tools, modes, and pedagogies available (Jaffe, 2015). Rather than seek the latest and greatest innovation, teachers may seek tools with the greatest impact for the lowest investment (e.g., time or money). Consequently, teachers are frequently drawn to multimedia; it is both relatively

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easy to integrate into existing classrooms and there is a wealth of research lauding its impact on learning.

The cognitive theory of multimedia learning (CTML) outlines numerous principles associated with learning from and with multimedia and the CTML has been applied to learners at all ages (Mayer, Hegarty, Mayer, & Cambell, 2005). Unfortunately, the bulk of work associated with multimedia and the CTML has been conducted using adult populations of students, particularly those who have already demonstrated some level of academic success (i.e., secondary school graduation and college acceptance). Due to key differences in age and academic progress, there remains a question of whether or not it is appropriate to generalize the CTML to adolescent students. Further, the idealistic context in which multimedia research is often conducted does not accurately reflect classrooms.

As a result, this research was designed to examine the learning benefits associated with multimedia and high school science students in an authentic classroom setting. Specifically, the study applied two principles that are prevalent in existing multimedia and classroom practices: animation and signaling. Specifically, the learning outcomes of high school student participants engaged with educational material that contained animations containing motion (with and without signaling cues) and were compared to the outcomes of students who experienced a sequence of static images (with and without signaling cues) in an effort to examine the influence of these multimedia principles on learning (i.e., the modality principle and signaling), as well as the generalizability of multimedia theory to adolescent populations.

REVIEW OF THE LITERATURE

Cognitive Theory of Multimedia Learning (CTML)

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 associated with cognition and media. Collectively, these efforts have been published as the Cognitive Theory of Multimedia Learning (CTML). The CTML outlines specific principles for researchers, educators, and instructional designers that are designed to maximize learning with and from multimedia. In the past several years, educators have applied the CTML and its principles to education at all levels and content areas, to mixed benefit (Leslie, Low, Jin, & Sweller, 2012; Luzon & Leton, 2015).

According to the theory, multimedia may be defined as a presentation or representation that combines words with visual material (Mayer, 2005). Words may be spoken or written, while visual material may be a picture, movie, diagram, graph, or animation. According to the CTML, an advantage of multimedia instruction is the ability for individuals to learn more from presentations that use visual and auditory components when compared to those that use only a visual or auditory element (Clark & Paivio, 1991). Ultimately, 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 Modality Principle

According to Mayer et al. (2005), there is an advantage in terms of cognitive load when a student interacts with a static image and written text versus a moving image with narration. Generally, static images are less cognitively demanding because the participant does not have to attend to the moving parts inherent to animations containing motion. Even when displaying static images 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). In this case, 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). Said another way, the animated example is potentially more demanding in terms of cognitive load. Due to the limited capacity of working memory (Sweller, 1994), the intrinsic load placed on a learner is usually fixed. However, the extraneous load, which is created by the presentation style, can be manipulated.

Considering extraneous load and manipulations of presentation style, the modality principle is particularly relevant to math and science content, which often exhibits high levels of intrinsic load (i.e., complexity of the content). In cases of highly complex content, narrating instructions or explanations alongside visuals can serve to reduce extraneous load (Mousavi, Lowe & Sweller, 1995). 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).

Ultimately, Mayer (2009) reports positive results with a median effect size of 1.02 from seventeen experiments designed to test the judicious implementation of the modality principle (i.e., information is presented with illustrations or animations with narration compared to illustrations or animations with written text). Further, there is some indication that research conducted with math and science based lessons have demonstrated enhanced learning when narrations were used instead of printed text (Jeung, Chandler, & Sweller, 1997; Lowe & Sweller, 2005; Moreno & Mayer, 1999). Less is known about animations and narration when it comes to K-12 classrooms.

The Signaling Principle

According to the CTML, another way to direct the learner's attention is to use signals or cues when key information is presented via multimedia (Mautone & Mayer, 2001; Moreno, 2007). In classrooms, teachers often cue students to information via a phrase (e.g., "this is important" or "this will be on the exam"), formative questioning, or outlining and note taking techniques. In multimedia, signaling can be accomplished through 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. 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 small, but positive effects (Mayer, 2005).

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).

In science, the presence of signaling may reduce the cognitive load to sufficiently offset negative effects illustrations may place on students with lower abilities (e.g., prior-knowledge; McTigue, 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. Unfortunately, there is little research on exactly how to produce positive results (de Koning et al., 2009).

Spatial Contiguity and Spatial Ability

Another key factor associated with multimedia learning is the positioning of words near pictures, or spatial contiguity (Mayer, 2005). According to research, 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 (Mayer, 1998; Sweller, Chandler, Tierney, & Cooper, 1990). For example, students who received instructions and diagrams together could transfer more information and solve problems better than a group who receive separated instructions and diagrams (Mayer, 1998; Tindall-Ford, Chandler, & Sweller, 1997). Similarly, placing math symbols that describe each step of a problem near the corresponding diagram increased knowledge transfer scores (Sweller et al., 1990). This orientation helps 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.

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. However, there is a wide range of ability when it comes to spatial reasoning and skills, particularly as it relates to the use nonlinguistic information that includes the transformation, recall, representation, and generation of symbolic information (Cherney & Neff, 2004). Further, prior research 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). Research involving animations should also examine spatial ability as a potential mediating variable.

CTML in Classrooms

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). The National Research Council (2007; 2009) set goals in the United States to promote spatially literate students that can use spatial thinking in informed ways (Jones et al., 2010). Teachers play a pivotal role in determining what visual-spatial resources are brought into the classroom (Mathewson, 1999) and there is a preponderance of information delivered to students via multimedia (e.g., visual aids found in science textbooks, electronic tablets, streamed video content, web pages, blogs, wikis, animations, and PowerPoint presentations). For many, the CTML serves as a basis for multimedia integration in K-12 settings (e.g., Leslie, Low, Jin, & Sweller, 2012; Luzon & Luton, 2015).

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 overloading the cognitive abilities of the learner and subsequently inhibiting learning (Ayres, 2006). Designing educational material that lowers the cognitive demands on the learner and facilitates comprehension and acquisition of newly learned materials remains a high priority for teachers and instructional designers. For example, Bruning, Schraw, Norby, and Ronning (2004) suggest 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.

Evidence-based research in cognition and pedagogy that accounts for limitations of working memory has also 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) recommends 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. More importantly, there remains the question of whether or not multimedia have cognitive advantages as described by the CTML when considering younger populations, e.g., high school science students in traditional classroom settings.

Need for Research into CTML with Younger Students

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 (McTique, 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 (Jones, Gardner, Taylor, Wiebe, & Forrester, 2010). Specifically, due to the presence of more robust schemas established in their long-term memories, experienced learners require less working memory to organize and integrate new information.

Overall, the individual differences between the two groups like age and demonstrated academic achievement are among the reasons to believe that these groups may differ in their abilities. At a minimum, classroom settings are characterized by curricular goals and objectives, which are generally absent from research on multimedia. For these reasons, it is not necessarily appropriate to generalize the findings of the CTML, no matter how robust, to adolescent learners in classroom settings.

Unfortunately, the research establishing the main principles of the CTML has predominately been conducted with college-aged students in laboratory settings with technical content designed specifically for the study (e.g., inner workings of car brakes, bicycle pumps, human lungs, lightning; McTigue, 2009). 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 et al., 2005). Considering the limited research conducted on precollege populations, the contrived contexts that do not follow curricular objectives or goals, and the technical multimedia content (i.e., not grade level), there is a need to examine multimedia learning with K-12 students in an authentic context.

As a result, numerous researchers have questioned the generalizability of the CTML to adolescent populations (Mayer et al., 2005; Reiber, 2005). Reiber (2005) points 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). Meyer et al. (2005) add, "the results might not generalize to population that includes lower ability or lower literacy individuals" (p. 264). To address this issue, evidence-based research is needed 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.

Ultimately, there remain numerous questions from the previous research associated with the CTML and adolescents. For example, what role does motion play in instruction from multimedia when working with younger students in an authentic setting? Similarly, in what ways does signaling influence multimedia learning? Finally, 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? These three questions highlight key components associated with the CTML and are outlined below within the context of this research:

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?

METHODS AND PROCEDURES

This mixed-methods research applied an experimental design within an authentic educational setting to examine the research questions. Approximately 100 high school science students were randomly assigned to one of four conditions, in which presentations used either motion or a sequence of static images to present content on the solar system and tides, with or without signaling words at key points during the presentations. A General Linear Model using Repeated Measures was applied to the data in this study. Specifically, 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. Previous research has linked students' ability to learn abstract science concepts to their spatial ability (Guillot et al., 2007; Jones et al., 2010; Stull et al., 2009). As a result, a test of spatial ability (i.e., the Vandenburg and Kuse Mental Rotation Test (MRT), 1978) was used as the covariate.

Three dependent variables were used to assess learner outcomes: (a) scores from a 14 item multiple-choice knowledge measure (KR20 = .601); (b) scores from a concept mapping task to examine knowledge synthesis and structure; and (c) responses from four Lickert-type questions associated with animation. Examples items are listed in Table 1.

Table 1. Sample Questions from Multiple-choice Assessment

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. Mar's 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?
   F. Once a day
   G. Once every seven days
   H. Once every twenty-seven days
   İ. Once every 30 days
   J. 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?
   K. The gravitational forces of the sun and moon work together to create very large tides.
   L. The gravitational forces of the sun and moon work against each other to create very small tides.
   M. The phase of the moon is in what is called a first quarter moon
   N. The phase of the moon is in what is called a second quarter moon
   O. This phase of the moon is in what is called a third quarter moon

Based upon previous research and approaches to concept maps (see Ingec, 2009; Jacobs-Lawson & Hershey, 2002; McClure, Sonak, & Suen, 1999; Ruiz-Primo & Shavelson, 1996; Yin, 2008), a 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 related to the presentation content (i.e., moon, tides, sun, earth, and astronomy). Cohen's Kappa statistic was used to calculate the reliability between two raters for pretest and post-test concept maps (.929 and .938, respectively).
The third dependent measure used in this research measured the cognitive difficulty of learning from the animations. This assessment contained four questions using a 9-point Likert-type scale (very, very difficult (1) to very, very easy (9)) pertaining to: (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.

Each measure was administered before and after treatment using a paper and pencil format.

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. Principles of modality, segmenting, temporal contiguity, and redundancy were applied when designing the presentations to either eliminate or significantly reduce cognitive load, confounding variables, and information non-equivalence. 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 (see Tversky et al., 2002) and the methodological confounds inherent when comparing learning from two media such as written words on paper to narrations.

Procedures

The pretest conditions occurred one week before the treatment and post-test conditions. The pretests (i.e., knowledge measure, concept map, and MRT) were administered in a science classroom while the post-tests (i.e., knowledge measure, concept map, and cognitive load measure) and treatment were administered in a computer lab the following week. 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.

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.

RESULTS

Participants

Participants in this study were high school students who ranged in age from 14 to 18. A total of 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. Students were recruited from conceptual physics, biology, and zoology courses from a high school located in the Southwestern United States. According to 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 (CCSD, 2016).

RQ1 and RQ2. All data were screened for outliers and the variables were analyzed for normality. Using standards established by Tabachnick and Fidell (1996) and Morgan and Griego (1998), no issues were detected. The total correct responses for knowledge, sums for each concept map category, raw scores for cognitive load, and the aggregate score for MRT were used in the General Linear Model with Repeated Measures Analysis of Covariance (RMANCOVA)).

Results of the RMANCOVA indicated statistical significance for the within subjects effect over time for all participants [Pillai's Trace = .203, $F (4, 90) = 5.736$, $p < .001$, $\eta\rho 2 = .203$]. The covariate, Vandenberg Kruse MRT was found to be significant, [Pillai's Trace = .222, $F (4,90) = 6.404$, $p < .001$, $\eta\rho 2 = .222$]. The MRT mean score was 16.67 from a possible total of 40.

Follow up univariate tests were used to examine within subjects differences. Analyses indicated that there was a significant effect with time and knowledge retention measured from the multiple-choice results [$F (1,93) = 19.042$, $p < .001$, $\eta\rho 2 = .170$]. Although there were no significant differences between groups for knowledge retention, analysis of learning gains by group (static and motion) and by treatment (signaled or non-signaled) show mean scores increased from pretest to post-test in both cases (see Figure 1).

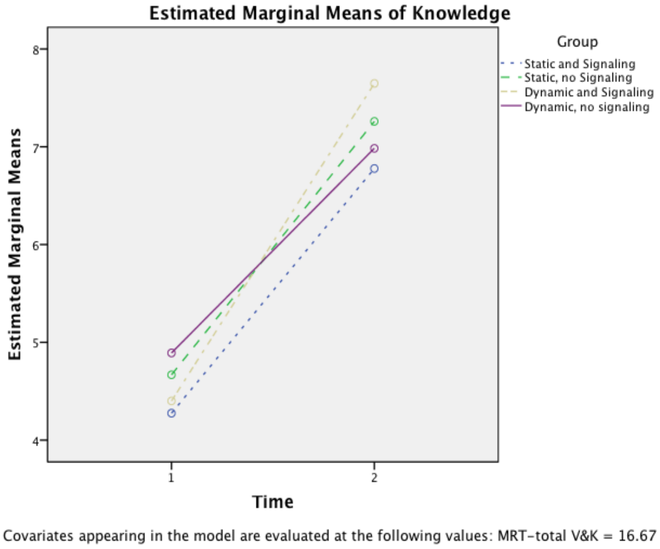

Figure 1. Estimated Marginal Means Over Time for Knowledge from the Knowledge Measure.

There were no significant gains for the category number of concepts represented in the concept map. Further, there was no significant difference between treatment groups for any of the concept map variables. Similarly, results indicated that the interaction of concept map variables (number of concepts, levels, and quality of concepts) among groups over time was not significant.

However, univariate follow up tests were also conducted on the concept map variables. These results indicated that the quality of concepts represented in the concept map analysis was significant [$F(1,93) = 5.712$, $p = .019$, $\eta\rho 2 = .058$]. Figure 2 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 was no significant difference between treatment groups for any of the concept map variables.

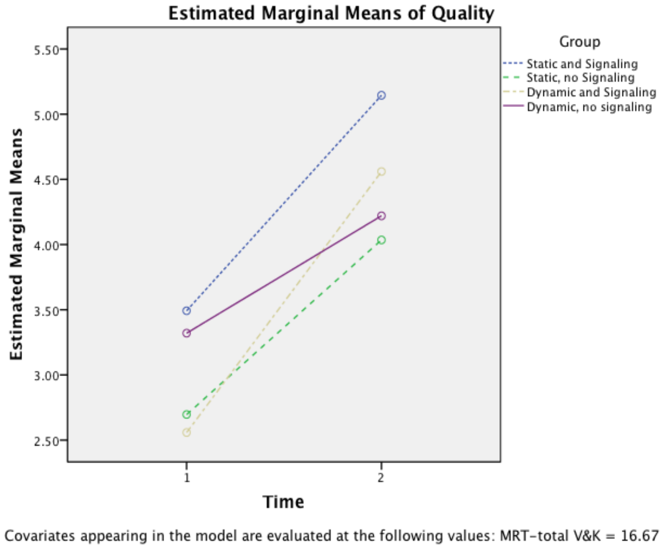

Figure 2. Estimated Marginal Means over Time for Quality of Concepts from Concept Map Assessment.

RQ3. 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 analyses were conducted.

DISCUSSION AND CONCLUSIONS

This research was designed to advance the empirical research associated with younger students and their learning benefits from multimedia, much like Mayer and colleagues have described (Mautone & Mayer, 2001; Mayer et al., 2005; Mayer & Johnson, 2008). For this study, an experimental design 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 and to determine whether or not the CTML was generalizable to authentic, K-12 classroom contexts.

By contrast to what might be expected from the CTML and related research, there were no significant differences among the groups. Specifically, the incorporation of motion and signaling did not yield a differential impact on learning outcomes associated with knowledge recall or students' knowledge structures. Rather, the findings indicated that all students demonstrated significant gains in terms of their knowledge scores and quality of concept maps regardless of treatment condition (i.e., motion vs. static or signaling vs. non-signaling). Figures 3, 4, 5, and 6 represent these gains.

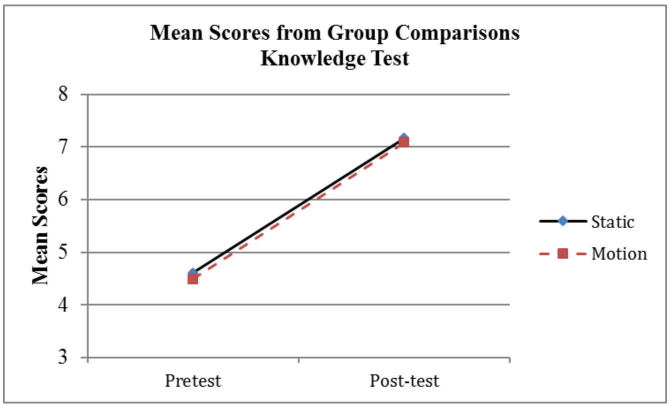

Figure 3. Comparison of Mean Pretest and Post-test Scores for Knowledge Measure by Group

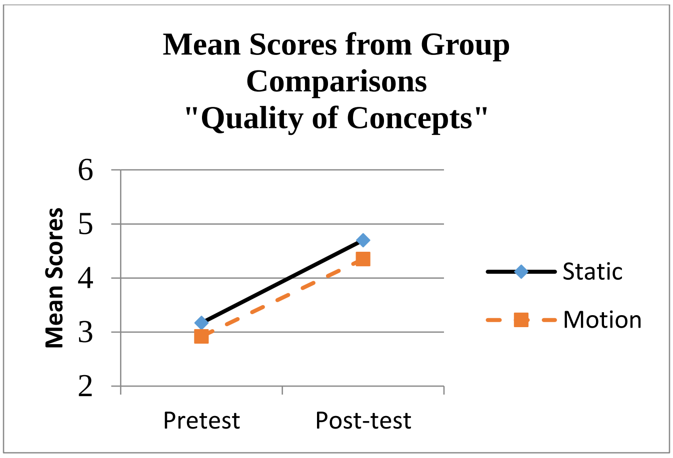

Figure 4. Comparison of Mean Pretest and Post-test Scores for Quality of Concepts by Group.

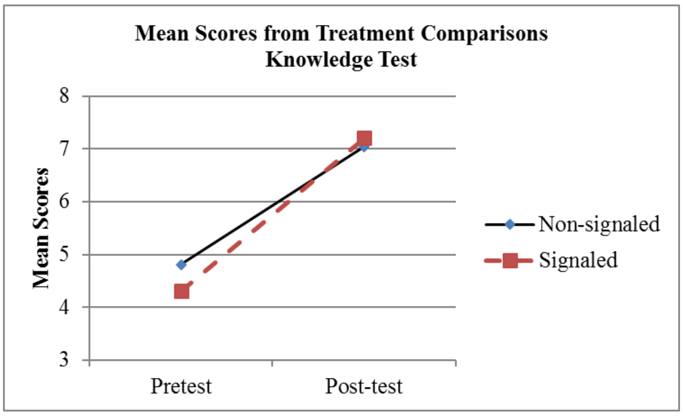

Figure 5. Comparison of Mean Pretest and Post-test Scores for Knowledge Measure by Treatment.

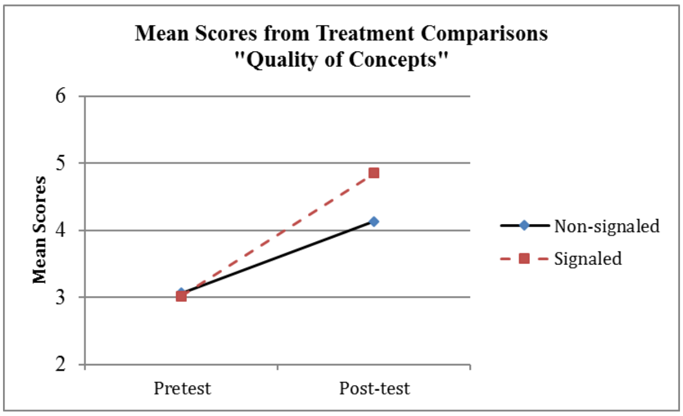

Figure 6. Comparison of Mean Pretest and Post-test Scores for Quality of Concepts by Treatment.

There may be numerous reasons for the lack of group differences that would be predicted by the CTML. First and foremost, this research was conducted in a classroom and the content was related to the classroom material. Although the research was not tied to their classroom grade, students may have felt more invested in the material because it related to their content. By contrast, existing CTML research leverages college students and content they are not specifically studying. Given that there is no extrinsic requirement to learn the material, one might conclude that ONLY the intrinsic goals are relevant to the outcomes. The relevance of goal orientation and motivation is not a part of this research and should be explored in the future.

Another issue may stem from the nature of the multimedia content. A classroom teacher designed the material for the specific purpose of teaching content. Further, the teacher implemented design that was directly informed by the CTML. Although the modality and signaling principles varied in terms of how they were implemented, all other components followed design that was informed by research. As a result, there may not have been enough opportunity for the two principles under investigation to influence learning outcomes, particularly in a classroom context. Said another way, all students received instruction and there was information equivalence across the multimedia examples; manipulations (i.e., motion and signaling) of the principles may not have been able to promote statistically significant differences in outcomes. Further, there may not have been enough new content to master (i.e., breadth) and/or the instruments may not have been precise enough to detect differences if they exist.

However, one might also argue that if a more careful and contrived approach to the multimedia design were necessary to promote differences in outcomes, then teachers would rarely go to these lengths to guarantee those differences. Typically, teachers seek existing animations that demonstrate related concepts rather than create them for their classroom. In this research, a high school teacher made decisions that were informed by the CTML when they created the materials. These tools were subsequently implemented in an authentic classroom. The fact that all learning outcomes increased, regardless of the manipulation of motion or signaling, may have more to do with the choices in creating good media (i.e., informed by the CTML) and less about manipulating variables (i.e., motion or signaling).

Unlike experimental contexts that are typical of CTML research, classroom contexts are entangled with informational equivalence and a culture of learning. Students tacitly understand and accept that their primary job is to learn, regardless of the quality or nature of the delivery mechanisms. Regardless of our ability to confirm and expand the modality principle and the relevance of signaling for learning, this research does suggest that educational multimedia, designed with the CTML in mind, has a positive influence on learning. Although the CTML may not necessarily generalize to classroom contexts in specific ways, it would appear that the principles apply in general ways to student learning, particularly as teachers make choices about the materials they introduce to students.

INSTRUCTIONAL IMPLICATIONS

The results from this study have implications for the CTML and may provide valuable information for instructional designers and teachers. Teachers who 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 are present rather than the static or dynamic nature of the animation. Further, 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) may be more predictive of student performance.

Additionally, applying the CTML principles may 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. Although more research is necessary to fully generalize the CTML to adolescent populations in complex classroom contexts, this research supports the CTML in terms of multimedia design, based on the affordances of the visual and auditory channels. By using appropriate design strategies for creation or selection of classroom materials, teachers can help facilitate learning in the classroom.

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APPENDIX A: 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. Mar’s 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 then 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

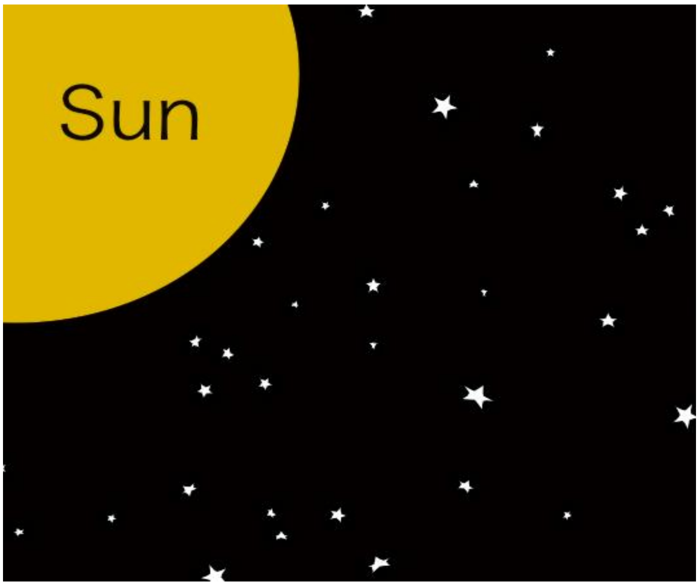
12. Which of the following statements is the most accurate concerning ecosystems?

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?

P. The moon is in the full moon phase and this is creating the largest tides on Earth
Q. The Moon is in the half moon phase and this is creating the largest tides on Earth
R. The Moon is in the new moon phase and this is creating the smallest tides on Earth
S. The Earth is entering the summer season, which will create the largest tides on Earth
T. 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