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The Effect Of Cognitive Aging On Multimedia Learning

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THE EFFECT OF COGNITIVE AGING ON MULTIMEDIA LEARNING

by

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ABSTRACT

If not designed in consideration to the workings of the human mind, multimedia learning environments can impose too high a demand on working memory. While such high cognitive load presents challenges for learners of all ages, older learners may be particularly affected as research on cognitive aging has shown the efficiency of working memory declines with age. Research has suggested that cognitive load theory (CLT) and the cognitive theory of multimedia learning (CTML) are likely to accommodate the cognitive needs of older learners; however, few of the principles emerging from these theories have been examined in the context of cognitive aging. The abundance of studies has focused on younger learners, prompting the need for further research of CLT and CTML principles with regard to age.

This study contributes to the body of research on the cognitive aging principle by extending research on the modality effect with middle-aged learners. Ninety-two participants ranging in age from 30 to 59 were exposed to multimedia learning treatments presented as animation with concurrent narration and animation with concurrent text, followed by retention, concept, and transfer tests of multimedia learning. Demographic and descriptive statistics were performed along with a multivariate analysis of variance. The findings did not show a modality effect with middle-aged learners; however, results need to be interpreted with care as possible explanations may entail other causes for the lack of a modality effect other than age.

This dissertation is dedicated to my wife, Wendy, and daughter, Emily.

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LIST OF ACRONYMS/ABBREVIATIONS

AN	Animation with Concurrent Narration
ANOVA	Analysis of Variance
AT	Animation with Concurrent Text
CLT	Cognitive Load Theory
CTML	Cognitive Theory of Multimedia Learning
LTM	Long-Term Memory
MANOVA	Multivariate Analysis of Variance
STM	Short-Term Memory
SE & IT	Systems Engineering and Information Technology

CHAPTER ONE: INTRODUCTION

Background

Historically, the potential for the improvement of learning through the use of technology has not translated very well into everyday practice. Technology and learning have had an intertwined past of failing to deliver on expectations. In fact, excitement surrounding the prospect of new technology for instruction can be found throughout the twentieth century. Probably the most cited example being Thomas Edison who in 1922 prophesized "…the motion picture is destined to revolutionize our educational system and that in a few years it will supplant largely, if not entirely, the use of textbooks" (cited in Cuban, 1986, p. 9). Regrettably, while theories are vocalized and debates rage over causes of learning and technology failures, advancements in technology continue to outpace research on their educational effectiveness.

What's more, with today's technology the learner is no longer in a passive learning mode but is increasingly exposed to information presented in multiple modes (i.e., verbal and pictorial representations) accessed through different sensory modalities (i.e., auditory and visual senses). This creates a quandary to the learner as some theories in cognitive psychology suggest working memory—a system that temporarily stores and manages information for performing complex cognitive tasks—is limited in capacity (Baddeley, 1986, 1998, 2002). Furthermore, research on cognitive aging suggests a decline of information processing ability attributable to age (Paas, Van Gerven, & Tabbers, 2005; Van Gerven, Paas, & Tabbers, 2006). While the multimodal nature of multimedia learning environments may be cognitively demanding on learners of all ages, these environments may be particularly overwhelming to older learners (Van Gerven, Paas, Van Merrienboer, & Schmidt, 2000).

Considerable research exists on the instructional design of multimedia learning environments. However, research has predominately focused on younger learners. Little is available on the effectiveness of these learning environments for older learners (Van Gerven, Paas, & Tabbers, 2006). This is unfortunate as more than half of the nation now uses computers and the Internet. Although children and teenagers are the largest group to benefit from these technologies, the elderly are among the fastest adopters. Furthermore, those using computers and the Internet will more than likely continue to do so as they age. For that reason, use of these technologies among the elderly is projected to steadily increase (National Telecommunications and Information Administration & Economics and Statistics Administration, 2002).

Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006) have suggested existing theories of cognitive aging and instructional design can serve as the foundation in creating sound multimedia learning environments for older learners. Chandler and Sweller's (1991; Sweller, 1999; Sweller, van Merrienboer, & Paas, 1998) cognitive load theory (CLT) and Mayer's (2001, 2005c) cognitive theory of multimedia learning (CTML) have been argued as two such instructional theories. Although these theories have shown potential benefit to younger learners, they may be especially applicable to older learners as both theories are concerned with the cognitive limitations of working memory. Subscribing to this line of thinking, the present study seeks to examine existing principles of CLT and CTML with regard to age.

Clarification of Terms

Given the purpose of the present study, age groups need clarification. *Younger* learners are clarified to mean individuals in their teens or 20s; *middle-aged* learners are clarified to mean individuals in their 30s, 40s, or 50s; whereas *older* learners are clarified to mean individuals 60 years of age or older. These age groups are based on the sampling of participants in CLT and CTML related studies. Although related studies investigating age have solicited learners 61 to 76 years of age (e.g., Paas, Camp, & Rikers, 2001; Van Gerven, Paas, Van Merrienboer, Hendriks, & Schmidt, 2003; Van Gerven, Paas, Van Merrienboer, & Schmidt, 2002, 2006), the present study investigates middle-aged learners 30 to 59 years of age. To avoid misunderstanding with the age group selected, a look at previous research is provided.

Typically, the elderly have been sought in CLT and CTML related studies investigating age (e.g., Paas et al., 2001; Van Gerven et al., 2003; Van Gerven et al., 2002; Van Gerven, Paas, Van Merrienboer et al., 2006). This should come as no surprise as most research on cognitive aging has suggested that cognitive abilities begin to slightly decline in the late 50s to early 60s, with noticeable effects not showing until the 70s. Bear in mind, however, that these are general findings with regard to normal aging. There is research which suggests that age-related cognitive decline may occur much earlier in life. For example, research has shown a steady decline in some cognitive abilities beginning as early as the late 20s and 30s. Conversely, other research has shown a steady increase for abilities well into the 50s and 60s (see Fergus I. M. Craik & Salthouse, 2000, for an in depth review).

Regrettably, middle-aged learners have not been factored into CLT and CTML related studies investigating age. In fact, this age group cannot be found in CTML related studies in general, as these studies have typically used 18 and 19 year old learners (e.g., Mautone & Mayer, 2001; Mayer & Chandler, 2001; Mayer, Fennell, Farmer, & Campbell, 2004; Mayer, Hegarty, Mayer, & Campbell, 2005; Mayer & Jackson, 2005; Mayer, Johnson, Shaw, & Sandhu, 2006; Mayer & Massa, 2003; Mayer, Sobko, & Mautone, 2003; Moreno & Mayer, 2004, 2005) with a few studies using learners in their 20s (e.g., Mayer & Jackson, 2005; Moreno & Flowerday, 2006; Moreno & Mayer, 2005). Although the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006) is described with regard to older learners, middle-aged learners are investigated in the present study to account for the full breadth of research on cognitive aging and to address the lack of research with this age group.

Furthermore, several CLT and CTML related studies have examined results of commonly used instructional methods on learning analyzed from the perspective of relevant aspects of human cognition. These findings have been referred to in the literature as *effects*. Some of which are shared between CLT and CTML. Effects describe an observable phenomenon that obstructs meaningful learning due to excessive cognitive load on working memory. Subsequently, *principles* have flowed from these effects, which provide instructional recommendations and guidance in handling the phenomenon. The goal of these principles is to facilitate meaningful learning by reducing or eliminating unnecessary cognitive load on working memory. Under certain, well-defined conditions, these principles can expand effective working memory capacity, thus reducing the negative effects of excessive cognitive load. However, the terms effect and principle have been used interchangeably within the literature. Therefore, to avoid misunderstanding in the present study, the term effect is used when referring to the observable phenomenon; whereas the term principle is used when referring to the corresponding instructional recommendation.

Chapter Organization

The present study is introduced in five major sections. In the remainder of this chapter, rationale for the present study is offered. The statement of the problem, purpose, research question and hypotheses, operational definitions, synopsis of the research design, overviews of the theoretical and empirical foundations, and significance are presented. In chapter two, a synthesis of the most current research on cognitive aging as it applies to CLT and CTML is discussed. In so doing, the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006) is presented. In chapter three, the research design for the present study is outlined. This includes a discussion of the participants and sampling methodology, interventions, instruments, procedure, scoring, data analysis, and disclosure of known methodological limitations. In chapter four, research findings are presented, while finally, in chapter five, conclusions are offered based on the findings along with implications and recommendations for ensuing research.

Statement of the Problem

Research in support of multimedia learning has shown that under certain conditions, a deeper understanding of instructional material can be obtained more efficiently from words and pictures than from mere words alone (Mayer, 2005a). If not designed in consideration to the workings of the human mind, though, multimedia learning environments can impose too high a demand on working memory. Such high cognitive load presents challenges for learners of all ages. Those which may be particularly affected are older learners, represented in the research on cognitive aging that suggests the efficiency of working memory declines with age (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006). Paas, Van Gerven, and Tabbers (2005) have formulated four views of age-related cognitive decline based on the most accepted explanations found in cognitive aging research. They have proposed that older learners suffer from reduced working memory capacity, slower processing speed, difficulties inhibiting extraneous or irrelevant information, and deficits in integrative or coordinating aspects of working memory. This degeneration of working memory severely impairs the learner's ability to engage in meaningful learning.

Instructional theories, such as CLT and CTML, both of which compensate for the aforementioned explanations of working memory decline, are likely to accommodate the cognitive needs of older learners (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006; Van Gerven et al., 2000). Few of the principles emerging from either theory, though, have been examined in the context of cognitive aging (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006). Of the research that does exist (e.g., Paas et al., 2001; Van Gerven et al., 2003; Van Gerven et al., 2002; Van Gerven, Paas, Van Merrienboer et al., 2006), focus has surrounded exploration of the cognitive aging principle, studied under the milieu of the modality effect, worked example effect, and goal-free effect with older learners. These studies, however, have focused exclusively on CLT. Although preliminary findings have shown some promise, further research is needed to study the cognitive aging principle with other CLT and CTML principles to include modality (Paas et al., 2005).

Purpose of Study

The present study seeks to contribute to research on the cognitive aging principle by investigating the modality effect with middle-aged learners. To accomplish this, the Mayer and Moreno (1998) study was replicated, which tested the applicability of the dual-processing theory of working memory to multimedia learning. By testing the premise that visual and auditory presented material is, at least initially, processed in separate areas of working memory (i.e., separate processing channels for visual and auditory represented material), Mayer and Moreno were able to extend the work of Mousavi, Low, and Sweller (1995) on the split-attention effect with regard to multimedia. The Mayer and Moreno research was the first to test the hypothesis that learners learn more from multimedia learning environments presented as animation and narration than animation and printed text. Their research serves as the pilot study in CTML for the modality effect or what would become the modality principle. It is for this reason that the Mayer and Moreno study was selected for replication.

From the two experiments, experiment one from the Mayer and Moreno (1998) study was reproduced. Similar treatments (i.e., the formation of lighting) and instruments (i.e., a participant experience questionnaire and retention, concept, and transfer posttest) to those used in Mayer and Moreno were leveraged along with a similar procedure. Unlike Mayer and Moreno, however, which used a subject pool of young college students, the present study introduces an older sampling. By drawing from a pool of middle-aged learners, the present study examines the modality effect with regard to age, consequently contributing to the cognitive aging principle. The present study also departs from Mayer and Moreno in that the experiment materials (i.e., treatments and instruments) were delivered online rather than paper-and-pencil. (Mayer and Moreno used paper-and-pencil to capture posttest answers of the animations viewed on a computer screen, whereas in the present study, posttest answers were captured electronically.)

Research Question and Hypotheses

The present study asks the question; does the modality effect apply to middle-aged learners in the context of multimedia learning? To be more specific, do middle-aged learners attain a higher degree of meaningful learning from animation with concurrent narration (i.e., pictorial and verbal presentation mode with visual and auditory sensory modalities) than animation with concurrent printed text (i.e., pictorial presentation mode with visual sensory modality)? The rationale behind this question is twofold. First, it is based on the premise that CLT and CTML can compensate for working memory decline and therefore are likely to accommodate the needs of older learners (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006; Van Gerven et al., 2000). Second, it stems from the need for further research on the cognitive aging principle (Paas et al., 2005). The question is answered by testing the following three hypotheses using retention, concept, and transfer posttests as a measure of meaningful learning.

Null Hypothesis I

There is no significant difference in the retention of relevant steps in the process of lightning formation (measured by retention posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

Null Hypothesis II

There is no significant difference in choosing the correct names for elements in an illustration of lightning formation (measured by concept posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

Null Hypothesis III

There is no significant difference in generating answers to problems on lightning formation that require applying learning to new situations (measured by transfer posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

Operational Definitions

The present study is dependent on an understanding of multimedia, meaningful learning, multimedia learning, the modality effect, and the cognitive aging principle. These terms are operationally defined for this specific study.

Multimedia

In the broadest sense, *multimedia* can be defined as the presentation of both words and pictures to a learner in a variety of ways. Words can be presented in verbal form and can be written or spoken. Either their phonological or semantic aspects can be emphasized. Pictures are presented in pictorial form and can consist of static or dynamic objects to include illustrations, photos, animations, or video. The pairing of presentation mode and sensory modality allow for many conceivable permutations (Mayer, 2005b; Reed, 2006). In the present study, the treatments describing the lightning formation process serve as the multimedia learning environment. The animation with concurrent text treatment is presented in both animation and written words (i.e., pictorial presentation mode with visual sensory modality); whereas the animation with concurrent narration treatment is presented in both animation and spoken words (i.e., the pictorial and verbal presentation mode with visual and auditory sensory modalities).

Meaningful Learning

Meaningful learning involves remembering and understanding presented material. Whereas remembering is the ability to recognize or reproduce presented material, understanding is the ability to construct sound mental representations from the material (Mayer, 2005b).

Meaningful learning occurs when important aspects of the material are cognitively recognized, when the material is organized into a coherent structure, and then integrated with relevant existing knowledge (Mayer, 1996, 2001; Mayer & Moreno, 2003; Wittrock, 1990). In addition, meaningful learning is distinguished by good retention and transfer performance. Retention is reflected in the ability to remember pertinent presented material. Transfer is reflected in the ability to understand what was learned and apply it to new situations (Mayer, 2002, 2005b). Transfer includes being able to solve new problems with knowledge that is not explicitly presented in the material (Mayer, 2005b). In the present study, meaningful learning is measured by retention, concept, and transfer posttests.

Multimedia Learning

Mayer (2001, 2005b) describes *multimedia learning* as the building of mental representations from the amalgamation of words and pictures, which induces the promotion of meaningful learning. For this reason, multimedia learning is measured in the present study by retention, concept, and transfer posttests when presented with multimedia learning treatments describing the lightning formation process.

Modality Effect and Principle

The *modality effect* occurs when material, such as text, is presented in an auditory rather than written mode when integrated with other non-verbal material (Sweller, van Merrienboer, & Paas, 1998; Tindall-Ford, Chandler, & Sweller, 1997), such as illustrations, photos, animations, or video. The modality effect occurs under split-attention conditions (Low & Sweller, 2005; Van Gerven et al., 2003). Split-attention occurs when multiple sources of information must be mentally integrated in a simultaneous manner before meaning can take place (Ayres & Sweller, 2005). The *modality principle* is an instructional recommendation flowing from the modality effect. The modality principle, under certain conditions, can effectively expand the capacity of working memory. Through presenting material in dual modalities (i.e., partly visual and partly auditory) the total induced load is spread across the visual and auditory components of working memory, thereby reducing cognitive load. Given the richness of multimedia learning environments, which can easily involve different presentation modes and sensory modalities, the modality effect is vital in the context of multimedia learning (Low & Sweller, 2005). In the present study, the multimedia learning treatments are presented using the modality effect. The animation with concurrent narration treatment represents the presentation of material in dual modalities; whereas the animation with concurrent text treatment serves as the comparison, represented in a single modality.

Cognitive Aging Principle

The *cognitive aging principle* is an instructional recommendation focused on helping older learners by effectively expanding the capacity of working memory (Mayer, 2005b). Subscribing to the idea that working memory capability declines with age (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006), the principle suggests that some instructional materials presented in multiple modalities may be more efficient than instructional material presented in a single modality. This is especially the case for older learners. Instruction aimed at older learners should be designed with their cognitive limitations in mind. The principle is based on the multimedia and modality effects (Paas et al., 2005) which have their roots in CLT and CTML. Although the cognitive aging principle has been studied with regard to older learners, in the present study, the cognitive aging principle is studied with regard to middle-aged learners. This age group is investigated to account for the full breadth of research on cognitive aging, which has suggested that age-related cognitive decline may occur much earlier in life, and to address the lack of research with this age group.

Overview of Research Design

To test the hypotheses presented, a two-group posttest only research design (Campbell & Stanley, 1963) was used. Participants were pooled from the systems engineering and information technology (SE & IT) division of a publicly held company headquartered in the northeastern part of the United States. As in experiment one of the Mayer and Moreno (1998) study, participants in the present study were exposed to multimedia learning treatments depicting the lightning formation process. Participants with little or no prior knowledge of meteorology received either the multimedia learning treatment presented as animation with concurrent narration or animation with concurrent text. One version of the multimedia learning treatment described the major lightning formation events in spoken words at a slow rate by a male voice; whereas the other version displayed the same spoken words on screen as text using the same timing. Both treatments mirrored those used in experiment one of Mayer and Moreno.

To measure multimedia learning resulting from the treatments, participants were given retention, concept, and transfer posttests. Like the treatments, the posttests mirrored those used in the Mayer and Moreno (1998) study. Individual scores were calculated for each participant for the three posttests using scoring rubrics. A multivariate analysis of variance was conducted to explore the differences in retention of relevant steps in the process of lightning formation, choosing correct names for elements in an illustration of lightning formation, and generating answers to problems on lightning formation between participants given the two treatments.

Overview of Theoretical Foundation

The *cognitive theory of multimedia learning* serves as the theoretical foundation for the present study. The theory was selected over CLT for the following three reasons. First, CTML provides a number of researched and well-documented effects along with corresponding empirically supported principles. The theory describes a human information processing system that if used together with the principles can provide best practices in designing sound multimedia learning environments. In other words, the theory was specifically developed for multimedia learning, making it the ideal choice given the nature of the present study. Second, existing research surrounding the cognitive aging principle predominately focuses on CLT; little has been done on multimedia learning. Third, CTML is based on three cognitive learning principles: (a) dual-channels assumption, (b) limited capacity assumption, and (c) active processing assumption (Mayer, 2005a). The limited capacity assumption is most consistent with CLT (Mayer, 2001, 2005a). Thus, some of the basic principles found in CTML have their origins in CLT, as is the case with the modality effect.

The following sections provide a brief overview of CTML. Basic and advanced principles are defined, including a discussion of the theory's shortcomings.

Dual-Channels, Limited Capacity, and Active Processing Assumptions

Three cognitive learning principles provide the theoretical underpinnings for CTML. The first of these assumptions, *dual-channels*, posits that the human information processing system is composed of a separate processing channel for visual and auditory represented material. Mayer (2001, 2005c) has conceptualized these dual-channels as a presentation mode and a sensory modality. The presentation mode addresses verbal (e.g., spoken or written words) and pictorial (e.g., illustrations, photos, animations, or video) representations of presented material. This notion best resembles Paivio's dual-coding theory (Clark & Paivio, 1991; Paivio, 1971, 1990) and borrows from the distinctions between the verbal and nonverbal subsystems (Mayer, 2001, 2005a). Sensory modality, on the other hand, deals with the sense through which the presented material is processed. For example, learners may initially process presented material through their eyes or ears. One channel processes verbal represented material, whereas the other channel processes auditory represented material. This notion is consistent with Baddeley's (1986, 1998, 2002) model of working memory and borrows from the distinctions between the visuospatial sketchpad (formally scratchpad) and the phonological (formally articulatory) loop (Baddeley, 2002; Mayer, 2001, 2005a).

The second assumption, *limited capacity*, has already been discussed to some degree. The assumption posits that working memory is limited in how much information can be processed within each channel. Unprocessed information that cannot be handled immediately decays over time. This notion is most consistent with Baddeley's model of working memory as well as CLT (Mayer, 2001, 2005a).

The last assumption, *active processing*, posits that humans must actively engage in cognitive processing for learning to occur. Mayer has identified three processes required for this to take place. First, relevant incoming information must be cognitively recognized and selected. In other words, the learner must be actively paying attention for the relevant information to be brought into working memory. Second, the incoming information must be organized into a coherent structure. This involves constructing a logical mental representation (i.e., model) of the elements composing the selected information within working memory. Finally, the organized information must be integrated with relevant existing knowledge found in long-term memory

(Mayer, 1996, 2001; Mayer & Moreno, 2003; Wittrock, 1990). These three assumptions are represented in the cognitive model of multimedia learning found in Figure 1.

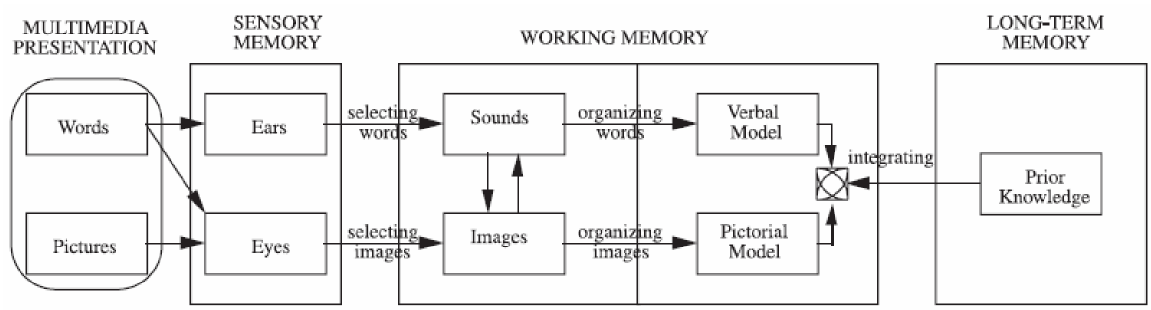


Figure 1. Cognitive model of multimedia learning[1]

To provide an example, multimedia (presented in words and pictures) enters sensory memory through the eyes and ears. This permits the information to be held as visual and auditory images for a brief period until such time that the relevant incoming information is selected and brought into working memory. Once in working memory, the incoming information is stored as raw material based on the visual and auditory sensory modalities. This information is then organized into coherent mental representations as verbal and pictorial models. Finally, the organized verbal and pictorial information is integrated with each other and relevant existing knowledge from long-term memory. This newly integrated knowledge is persistently stored in long-term memory resulting in multimedia learning.

Basic and Advanced Principles

A number of evidence-supported effects have emerged from CTML. Mayer (2005b) has logically divided these effects into two groups of principles, basic and advanced. The basic principles make up the cornerstone of CTML. In fact, some of the basic principles serve as the theoretical foundation for other principles. For example, the multimedia principle—that states learners learn more from words and pictures than from words alone—is the basis for all CTML principles. It is embodied in 11 experiments across six studies (e.g., Mayer, 1989, Experiments 1 and 2; Mayer & Anderson, 1991, Experiments 2a and 2b; 1992, Experiments 1 and 2; Mayer & Gallini, 1990, Experiments 1, 2, and 3; Moreno & Mayer, 1999b, Experiment 1; 2002a, Experiment 1). It is one of the well-documented principles in CTML along with the modality and the contiguity (spatial and temporal) principles. The advanced principles, conversely, mark some of the most current research being conducted in multimedia learning. These principles, as expected, are the weakest in terms of empirically based research. A brief description of the basic principles (see Mayer, 2005b; Mayer & Moreno, 2003) can be found in Table A1 (see Appendix A, page 94); whereas the advanced principles (see Mayer, 2005b) can be found in Table A2 (see Appendix A, page 94).

Cognitive Theory of Multimedia Learning Limitations

The cognitive theory of multimedia learning has matured over the last 17 years, yet shortcomings can still be found with the theory. These shortcomings can be attributed to methodological limitations within supporting research. Although limitations could easily be described in the context in which they are studied (e.g., multimedia learning as it applies to chemistry, history, or mathematics), a broader approach is used instead. Namely, limitations are discussed which are consistently found across CTML related studies. Furthermore, this is done independent of their application. This amounts to four major categories: (a) setting and content, (b) sampling, (c) time, and (d) individual differences.

Laboratory versus real-world settings has long been a methodological concern. Early experiments were performed in controlled laboratory-like environments suggesting that CTML principles need further examination in real-world settings, such as the classroom. Content has also been an issue, as early treatments typically dealt with cause-and-effect subject matter. This has brought about the need to test CTML principles in the context of authentic learning environments using real-world content. The need for real-world testing and the exploration of advanced content have continuously been explicitly noted in a number of studies (e.g., Mautone & Mayer, 2001; Mayer & Chandler, 2001; Mayer, Heiser, & Lonn, 2001; Mayer & Moreno, 1998; Mayer & Sims, 1994; Moreno, Mayer, Spires, & Lester, 2001).

Sampling has also been a voiced methodological concern (e.g., Dunsworth & Atkinson, 2007; Mayer et al., 2001; Mayer & Moreno, 1998). Early experiments typically used college students from the psychology subject pool at the University of California, Santa Barbara. Consequently, CTML principles have been predominately tested with younger learners 18 and 19 years of age (e.g., Mautone & Mayer, 2001; Mayer & Chandler, 2001; Mayer et al., 2004; Mayer et al., 2005; Mayer & Jackson, 2005; Mayer et al., 2006; Mayer & Massa, 2003; Mayer, Sobko et al., 2003; Moreno & Mayer, 2004, 2005). Furthermore, other concerns have stemmed from sample size. These limitations have established the need to test CTML principles with larger samplings across different demographics, to include age, gender, and language.

The implication of time on multimedia learning has also been noted in studies (e.g., Craig, Gholson, & Driscoll, 2002; Mayer & Chandler, 2001; Mayer & Sims, 1994). Early experiments typically administered measures of multimedia learning immediately after exposure to treatment(s). In other cases, the treatment(s) themselves were relatively short in length. As a result, the depth of learning measured in these studies has been a concern, suggesting the need to test CTML principles in consideration to time. For example, would the principles produce the same depth of learning if delayed testing were used or if exposed to multimedia learning treatments for longer periods?

Finally, the matter of individual differences has been commonly identified as a limitation (e.g., Craig et al., 2002; Mayer & Anderson, 1992; Mayer et al., 2001; Mayer & Sims, 1994; Moreno et al., 2001). Many experiments have procedures to identify and preclude learners who can demonstrate a predetermined level of prior knowledge. This exclusion is based on the study by Mayer and Gallini (1990) (and subsequently Mayer and Sims (1994)), which concluded that learners with low prior knowledge had shown improved performance over those with high prior knowledge. Many studies, however, still argue the point that CTML principles need to be examined with high prior knowledge learners.

One final limitation of significant importance is the generalizability of the research findings. Although many studies have been performed, some of which examine the interplay of CTML principles, care should be taken in generalizing the use of these principles across content areas. Further research is needed.

The present study addresses two of the four methodological shortcomings discussed thus far. First, learners were exposed to the experiment materials (i.e., treatments and instruments) online, which were accessible from their typical computer workstation settings. That is, the present study uses a real-world setting rather than that of a laboratory. Second, the present study uses a sampling of older adults than those traditionally used in CTML related studies. In doing so, the present study takes into account the sampling methodological issues of the past by using middle-aged learners.

Overview of Empirical Foundation

The cognitive theory of multimedia learning has shown steady growth since the earliest studies in the 1990s exploring the plausibility of multimedia learning. The premise that learners learn more from words and pictures than from words alone was one of the first predictions made by Mayer and his colleagues based at the time on his generative theory. This of course would later become known as the multimedia principle, serving as the founding principle behind CTML. Mayer and his colleagues continued to explore numerous effects while developing recommendations and guidelines throughout the remainder of the twentieth century. These effects would later be described as principles and encompass over 80 individual experiments (Veronikas & Shaughnessy, 2005). A detailed matrix classifying experimental study by basic principle can be found in Appendix B (see page 97). The matrix displays the total number of experiments performed in support of each basic principle. While more experiments can be found in the literature, the experiments included in the matrix are those most frequently referenced as evidence in support of the basic principles (e.g., Mayer, 1997, 2003, 2005b; Mayer & Moreno, 2003).

In recent years, research in CTML has significantly grown. Although a substantial amount of research can be found exploring advanced effects and posturing new principles for how to design multimedia learning, an emerging trend points to the study of existing principles in various context areas. One such example is the study of multimedia learning in the context of advanced computer-based environments (Mayer, 2005b). For example, Mayer and his colleagues have of late been examining the use of animated pedagogical agents (Moreno, 2005). Mayer hypothesizes that the basic principles can be applied in the use of these agents (Veronikas & Shaughnessy, 2005). Other such examples include the examination of multimedia learning in the context of virtual reality (Cobb & Fraser, 2005) and games, simulations, and microworlds (Rieber, 2005). These contexts have already fueled a number of empirical studies (e.g., R. K. Atkinson, Mayer, & Merrill, 2005, Experiments 1 and 2; Dunsworth & Atkinson, 2007; Mayer, Dow, & Mayer, 2003, Experiments 1, 2a and 2b, 3, and 4; Merrill, 2003; Moreno & Flowerday, 2006; Moreno & Mayer, 2004; 2005, Experiments 1, 2, and 3; Moreno et al., 2001, Experiments 1, 2, 3, 4, and 5).

Subscribing to this trend, the present study seeks to contribute to research on the cognitive aging principle by investigating the modality effect with regard to middle-aged learners. Although the modality effect has been thoroughly studied, embodied as 10 experiments across four studies (e.g., Mayer, 1998, Experiments 1 and 2; Moreno & Mayer, 1999a, Experiments 1 and 2; 2002a, Experiments 1 and 2; Moreno et al., 2001, Experiments 4a and 4b and 5a and 5b), few studies have explicitly examined the modality effect in the context of age (e.g., Constantinidou & Baker, 2002; Van Gerven et al., 2003; Van Gerven, Paas, Van Merrienboer et al., 2006). As discussed in the shortcomings of CTML, existing studies have typically solicited participation from young college students.

Significance of Study

As advancements in multimedia technology continue to outpace research on their educational effectiveness and as elderly learners continue to be one of the fastest adopters to use computers and the Internet (National Telecommunications and Information Administration & Economics and Statistics Administration, 2002), it is anticipated that the relevance of cognitive learning theories to older learners will grow in importance. Regrettably, few principles emerging from CLT or CTML have been examined in the context of cognitive aging. The abundance of studies has predominately focused on younger learners, amplifying the need for research of CLT and CTML principles with regard to age.

Consequently, the present study should be of particular significance to educational researchers and practitioners within the instructional design community. Educational researchers should be largely interested in how age plays a role in the design of multimedia to promote learning. Furthermore, educators and trainers should also benefit from this knowledge. By understanding the implications of age on multimedia learning, educators and trainers should be able to select multimedia technologies to use in their instruction that more closely cater to their learners' needs. Moreover, it is instructional designers that should be challenged the most from the findings in the present study. As the number of life-long learners continues to increase along with wide-spread availability of multimedia, instructional designers may find themselves designing solutions that must accommodate age-related cognitive decline. It is hoped that the present study can inform instructional designers about optimizing and tailoring instruction to their learner's needs.

CHAPTER TWO: REVIEW OF LITERATURE

Though the argument exists that research synthesis is part art and part science, it is also widely accepted that literature reviews should be systematic in nature; following similar methodological processes as those who conduct primary research (H. Cooper, 2003). For that reason, the five stage research process (i.e., problem formulation, data collection, data evaluation, analysis and interpretation, and presentation of findings) proposed by Cooper (1982) was adopted for this literature review. Furthermore, and for clarity sake, this review is introduced using Cooper's (1988) six distinction taxonomy (i.e., focus, goals, perspective, coverage, organization, and audience) for categorizing reviews.

Focus, Goal, Perspective, Coverage, Organization, and Audience

This chapter focuses on literature related to the primary variables found in the present study to include literature on cognitive components related to aging and additional supportive literature on multimedia learning and how it can support older learners. This chapter specifically focuses on: (a) the cognitive aging principle, (b) cognitive aging, (c) human cognition and learning, (d) multimedia learning theories, (e) cognitive aging decline and proposed compensatory multimedia strategies, and (f) studies contributing to the cognitive aging principle. In doing so, the goal is to articulate the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006), who have suggested that existing theories of cognitive aging and instructional design can serve as the foundation in creating multimedia learning environments for older learners.

As previously outlined, an understanding of cognitive aging and multimedia learning should be intertwined in the development and delivery of effective multimedia learning environments to older learners. Paas et al. (2005) have argued that to exploit the benefits of these environments, an understanding of age-related cognitive changes must first be understood. This research is explained in terms of four views of age-related cognitive decline. First, the cognitive aging principle is introduced. Second, central findings of cognitive aging research as applicable to multimedia learning are presented. Third, an overview of human cognition and learning is provided to include the role of working memory and the dual-processing assertion. This overview provides the scaffolding needed to understand the instructional theories. Fourth, CLT and CTML, their associated research, and implications for instructional design are presented. In doing so, emphasis is placed on the modality effect because of the significant role it plays in the present study. Fifth, the four views of age-related cognitive decline are bridged to CTML principles as possible compensatory multimedia strategies. Finally, research studies contributing to the cognitive aging principle are discussed. Particular attention is placed on those studies investigating the modality effect.

Given the breadth of this review, an attempt was made to be exhaustive in character, demonstrating a comprehensive synthesis of literature. Studies were drawn from a variety of sources, including published articles, books, reports, and dissertations. Moreover, several data collection approaches were employed, including various electronic databases (e.g., Academic OneFile, Academic Search Premier, Dissertations & Theses: Full Text, ERIC, InfoTrac OneFile, JSTOR, OmniFile Full Text, PsycINFO, PsycARTICLES, SpringerLink, and WilsonWeb), abstracting services (e.g., Psychological Abstracts), online sources (e.g., Google Scholar), and general services (e.g., interlibrary loan). Data collection techniques also included both ancestry and descendency (e.g., The Social Sciences Citation Index) approaches (H. Cooper, 1998; H. M. Cooper, 1988). Although this review attempts to be a neutral representation of the literature, providing little along the lines of personal interpretation, this review does incorporate the perspective of Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006); as Cooper (2003) points out "…perfect neutrality is not a state found in nature" (p. 163). As for organization, studies are grouped conceptually and chronologically. Finally, this review provides theoretical and practical insight for both educational researchers and practitioners alike.

The Cognitive Aging Principle

Theories in cognitive psychology have suggested that working memory is limited in capacity (Baddeley, 1986, 1998, 2002). Research in cognitive aging has suggested a decline of information processing ability attributable to age (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006). The multimodal nature of multimedia learning environments may therefore be cognitively demanding on learners of all ages, but especially overwhelming to older learners (Van Gerven et al., 2000). This has caused researchers to question the extent to which older learners are capable of the integrative processing required by multimodal presentation (Paas et al., 2005).

Paas et al. (2005) have suggested cognitive changes as a consequence of age necessitate considerations for the design of multimedia learning environments. Van Gerven et al. (2000), Paas et al., and Van Gerven, Paas, and Tabbers (2006) have further argued existing theories of cognitive aging and instructional design can serve as the foundation in creating sound multimedia learning environments for older learners. These considerations largely relate to the cognitive aging principle. Both of these instructional theories may be especially applicable to older learners because these theories are concerned with the cognitive limitations of working memory.

Cognitive Aging

There are a number of structural and functional changes that occur in the brain throughout life. Some of these changes can be characterized by cell loss and widespread decline in neural and metabolic efficiency (Scheibel, 1996). Yet, the methods by which these changes influence the human information processing system are not well understood (Reutter-Lorenz, Stanczak, & Miller, 1999). Consequently, a number of theories have been proposed, one of the most popular being a decline in information processing resources as a result of age (e.g., Fergus I.M. Craik & Byrd, 1982; Hartley, 1992; Salthouse, 1988). Although cognitive aging researchers have offered various explanations for this decline, there does appear to be a consensus that the processing capacity needed for cognitive efficiency is influenced by age (Reutter-Lorenz et al., 1999). Needless to say, one of the central findings in cognitive aging research has been that age contributes to the decline of working memory (Paas et al., 2005). Hence, *cognitive aging* can be viewed as the decline of processes necessary for the effectiveness of information processing (Van Gerven, Paas, & Tabbers, 2006). Cognitive aging is a normal, age-related cognitive decline which is typically associated with a fall in working memory performance (Paas et al., 2005).

Paas et al. (2005) have formulated four views of age-related cognitive decline based on the most accepted explanations found in cognitive aging research. They have proposed that older learners suffer from: (a) reduced working memory capacity, (b) slowed processing speed, (c) difficulties inhibiting extraneous or irrelevant information, and (d) deficits in integrative or coordinating aspects of working memory. A discussion of these four views is given next.

Four Views of Age-Related Cognitive Decline

The first decline, *reduced working memory capacity,* suggests that the ability to engage in demanding operations necessary for meaningful learning to occur is impaired by the loss of available working memory capacity (Paas et al., 2005). It might be said that this decline is the most obvious cognitive change associated with aging (Van Gerven et al., 2000) as working memory plays such a critical role in meaningful learning. In fact, there is a substantial body of evidence in support of the hypothesis that complex cognitive operations, which require considerable processing, are the likely culprit for age-related cognitive decline (e.g., Gilinsky & Judd, 1994; Salthouse, Mitchell, Skovronek, & Babcock, 1989; Wingfield, Stine, Lahar, & Aberdeen, 1988). Consequently, as operations become more complex or require larger amounts of processing resources, older learners have more difficulty in learning novel instructional material (Paas et al., 2005).

The second decline, *reduced cognitive speed,* suggests that age-related cognitive decline results in a reduction of processing speed with older learners (Van Gerven et al., 2000). Reduction in speed has been one of the most observed and studied age-related differences in performance (e.g., Fisk & Warr, 1996; Salthouse, 1994, 1996; Salthouse & Babcock, 1991) and has led to a number of theories to include Salthouse's (1996) *processing-speed theory* and Myerson, Hale, Wagstaff, Poon, and Smith's (1990) *information-loss model*. Although theories have varied, researchers appear to be in agreement that age is associated with decreased speed and this reduction in speed results in an impairment of an older learner's ability to process novel instructional material.

The third decline, *reduced inhibition,* suggests that older learners have difficulty in the ability to discriminate between relevant and irrelevant information (Van Gerven et al., 2000). This decline is typically attributed to increased neural noise (see Welford, 1985), which is supported by numerous studies which have examined the performance of older learners in visual searching exercises (e.g., Allen, 1990; Allen, Madden, & Groth, 1992; Madden, Connelly, &

Pierce, 1994). Reduced inhibition is in line with the neural noise approach (Van Gerven et al., 2000) and proposes the existence of an active suppression or inhibition process that can operate directly on unselected or distracting information. This means that the ability to efficiently select information also includes the ability to suppress responses to irrelevant information (see Hartman & Hasher, 1991; Hasher & Zacks, 1988; Stoltzfus, 1993; Zacks & Hasher, 1997). However, the inability to suppress irrelevant or extraneous information poses additional work load on the cognitive system, of which older learners are most susceptible (Paas et al., 2005).

Finally, according to Paas et al. (2005), *reduced integration* decline has been grounded in motley of studies. For example, Light, Zelinski, and Moore (1982) are cited in connection with deductive reasoning. They found that older learners were not able to integrate information across several premises, regardless as to whether or not the premises could be accurately recognized. Studies cited regarding macrospatial research (comparing memory for routes of young and old learners) found that memory declined with age for both novel and familiar environments (e.g., Kirasic, Allen, & Haggerty, 1992; Lipman & Caplan, 1992). Meanwhile, Mayr and his colleagues (Mayr & Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996) have been described as using figural transformation tasks to show that slowing as a result of age is larger in coordinative complexity conditions than that of sequential complexity conditions (Paas et al., 2001; Paas et al., 2005).

Significance of Cognitive Decline

Given the aforementioned four views of cognitive decline, the importance of addressing the cognitive needs of older learners when presenting instructional material in multiple modes accessed through different sensory modalities, should be clear. Instructional design considerations must include sensory changes common among older learners, necessitating special attention to the presentation of visual and auditory represented material (Paas et al., 2005). This leads to the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006), who have proposed that existing theories of cognitive aging and instructional design can serve as the foundation in creating sound multimedia learning environments for older learners. Cognitive load theory and CTML support this line of thinking by bringing aging theories and instructional design together. To better understand these theories, a discussion of human cognition and learning is provided next as scaffolding, which includes the role of working memory and the dual-processing assertion.

Human Cognition and Learning

Traditionally, theorists and psychologists have depicted human memory as models composed of acquisition, storage, and retrieval stages, otherwise collectively referred to as *information processing models* (Brunning, Schraw, Norby, & Ronning, 2004). Although variations of these models have been abundant (e.g., R. C. Atkinson & Shiffrin, 1968; Norman, 1968; R. M. Shiffrin & Atkinson, 1969; Waugh & Norman, 1965), their common features have influenced a basic framework made popular over the past four decades called the *modal model of memory* (Healy & McNamara, 1996). This model postulates that human memory is composed of *sensory registers* (i.e., a sensory memory store), *short-term memory* (STM) (i.e., a primary memory store), and *long-term memory* (i.e., a secondary memory store) (LTM), each serving a specific function (Brunning et al., 2004; Healy & McNamara, 1996). The model is typically compared metaphorically with that of computer memory (R. C. Atkinson & Shiffrin, 1968; Brunning et al., 2004; R. M. Shiffrin & Atkinson, 1969). Though variations exist as to how learning takes place with regard to the modal model, it is generally agreed that information is transferred between memory stores using a variety of encoding and retrieval processes (Brunning et al., 2004).

For example, the sensory memory store is responsible for temporarily holding stimuli in sensory registers so that encoding may occur. Encoding consists of detecting incoming stimuli through attention then associating the perceived stimuli with a recognizable pattern. Stimuli that are both perceived and recognized travel to STM where the encoded information is processed for meaning. If the encoded information can be strengthened with relevant knowledge found in LTM, meaningful learning takes place and the elaborated information safely travels to LTM. If the encoded information cannot be fortified with pertinent knowledge from LTM, the information in STM is likely to be lost (Brunning et al., 2004; Gagné, Briggs, & Wager, 1992; Solso, 2001). Although the role of STM is vital in learning, regrettably, STM is believed to be limited in both capacity and duration.

Short-Term Memory Capacity and Duration Limitations

The earliest quantification of the capacity limit of STM is the landmark article by Miller (1956) who has suggested that an “informational bottleneck” (Summary section, ¶ 2) exists with regard to STM. Miller had argued that STM is limited to seven (plus or minus two) *chunks* (i.e., a meaningful sequence of information) at any given time. However, he had also argued that the capacity limit of STM could be stretched by increasing chunk size. An example of this is remembering a meaningful phone number as one or two chunks rather than a meaningless phone number as seven.

Research quantifying the duration limit of STM can also be found dating as far back as half a century. For example, Peterson and Peterson (1959) had demonstrated in two experiments that information in STM is quickly forgotten within about 20 s if not rehearsed. Early psychologists believed this decay of information was due to time (Brunning et al., 2004; Waugh & Norman, 1965). Subsequent studies (e.g., Waugh & Norman, 1965), however, have suggested interference caused by later information (i.e., items in a series) is more than likely the culprit of this information decay (Greene, 1992; Solso, 2001).

Working Memory

As an assortment of operations was being attributed to STM, little was being offered as to how these operations occurred. The complexities of STM eventually led cognitive theorists and psychologists towards proposing theoretical models explaining the information processing mechanics behind STM, or what would be called *working memory* (Brunning et al., 2004). Although the distinction between STM and working memory varies, in the broadest sense, STM can be viewed as an abstract and theory neutral premise explaining the temporary storage of information within behavioral psychology (e.g., Miller, 1956); whereas, working memory is much more theoretical in nature, explaining the processing of information within cognitive psychology (e.g., Baddeley, 1986; 1998).

Despite the fact that a number of theorists have created various models (e.g., MacDonald & Christiansen, 2002; Niaz & Logie, 1993), one of the most prominent contributors to the theory of working memory is Baddeley (1986, 1998, 2002), who has proposed the *model of working memory*. A three system model composed of an *executive control system*, a *phonological loop*, and a *visuospatial sketchpad*. The executive control system manages the two subsystems along with deciding what information to allow into working memory and what course of action to take to process the information once in working memory. The two subsystems, the visuospatial sketchpad and the phonological loop, hold and process information. For example, spatial information is handled by the visualspatial sketchpad, whereas acoustic and verbal information is handled by the phonological loop. According to Baddeley, these three systems work collaboratively to process all information in working memory.

Still, working memory suffers from the capacity and duration limitations believed to exist with STM. Cognitive psychologists see working memory as a limited capacity information processing system which temporarily stores and processes information for incorporation into LTM. It is believed that as storage demands increase, available processing resources decrease (Niaz & Logie, 1993). Furthermore, information which cannot be immediately committed to LTM simply decays (Baddeley, 1986, 1998). This poses a significant challenge, as these limitations can seriously hamper learning.

Dual-Processing Assertion

Unlike early theories which viewed STM as a single store capable of performing numerous operations (Sweller, 2005), working memory is assumed to be composed of multiple stores (Baddeley, 1986, 1998, 2002; Paivio, 1990; Penney, 1989; Sweller, 2005). Baddeley's model of working memory portrays numerous operations by handling visual and acoustic information individually with the visuospatial sketchpad and phonological loop subsystems. Making use of partial autonomy for processing visual and auditory information is believed to be a way in which to address the limitations of working memory. For example, Frick (1984) had investigated the idea of separate visual and auditory memory stores, showing how digit-span recall could be increased; Penney (1989), in a review, had provided evidence that appropriate use of the visual and auditory stores can increase working memory capacity. Although researchers seem to disagree on a common nomenclature, using terms such as *stores*, *channels*, *bisensory*, *dual-coding*, and *dual-processing* (e.g., Allport, Antonis, & Reynolds, 1972; Baddeley, 1986, 1998; Jones, Macken, & Nicholls, 2004; Mayer & Anderson, 1991; Paivio, 1971; Penney, 1989) to represent the components of working memory, they do seem to agree with the premise that dual-processing is vital towards overcoming the limitations of working memory.

This dual-processing assertion is best represented in Paivio's *dual-coding theory* (Clark & Paivio, 1991; Paivio, 1971, 1990), which has claimed that cognition is composed of verbal (i.e., verbal representational) and nonverbal (i.e., imagery) subsystems. These two subsystems are considered distinct, but interrelated. The verbal subsystem favors organized, linguistically based information, stressing verbal associations. Examples include words, sentences, and stories. The nonverbal subsystem, organizes information in nested sets, processed either synchronously or in parallel. Examples include pictures and sounds (Paivio, 1971, 1990; Paivio, Clark, & Lambert, 1988). Multimodal learning material, which can be coded in both subsystems, rather than just one, is more easily recalled. By leveraging both the verbal and nonverbal subsystems, more information can be processed.

Studies examining dual-coding have shown greater performance can be achieved when learners are presented with learning material that takes advantage of both the verbal and nonverbal subsystems (e.g., Frick, 1984; Gellevij, Van Der Meij, De Jong, & Pieters, 2002; Leahy, Chandler, & Sweller, 2003; Mayer & Moreno, 1998; Moreno & Mayer, 1999a). These findings are promising, as they suggest the limited capacity of working memory can be addressed by presenting learning material in a verbal and nonverbal manner (Mayer, 2001, 2005c; Sweller et al., 1998). More importantly, the converse has also been shown. The verbal and nonverbal subsystems are believed to pool from the same processing resources. As such, multimodal information that is not interrelated can negatively impact working memory performance (Morey & Cowan, 2004). Thus, the nonverbal instructional presentation of information should be relational to the verbal (textual), for it has a significant impact on working memory and learning.

Significance of Human Cognition and Learning

Working memory can therefore be seen as a contradiction in terms with regard to learning. Its limitations cause it to be a bottleneck; yet, it is also the conduit for learning. As a result, researchers are constantly exploring ways to best leverage the limited cognitive resources of working memory. This is most important when learning novel information because the acquisition of new knowledge relies so heavily on the processing and storage capabilities of working memory (Low & Sweller, 2005; Sweller & Chandler, 1994). Such novel information may potentially overload working memory capacity and subsequently encumber learning (Kalyuga, Chandler, & Sweller, 1999; Sweller et al., 1998). Fortunately, instructional theories, such as CLT and CTML, are believed to compensate for the aforementioned explanations of working memory decline.

Multimedia Learning Theories

With the four explanations of age-related decline in mind along with an understanding of the limitations of working memory and the importance of dual-processing, attention is now turned to CLT and CTML. Both theories are discussed along with their associated research and implications for instructional design. Although CLT is presented, importance is placed on

CTML, as this theory is the theoretical foundation for the present study. A discussion of CLT is given as a precursor to CTML, as the management of cognitive load plays a significant role in CTML (recall the limited capacity assumption discussed in chapter one). Furthermore, CTML is home of the cognitive aging principle. Although a number of effects have been studied regarding both theories, emphasis is placed on the modality effect because of its obvious significance in the present study.

Cognitive Load Theory

Considerable research has been done in studying cognitive load with regard to working memory. Even though some researchers have examined cognitive load under the premise of the *working memory overload hypothesis* (e.g., Niaz & Logie, 1993), the most predominant work on cognitive load can be attributed to *cognitive load theory* (e.g., Chandler & Sweller, 1991; Kalyuga, Chandler, Tuovinen, & Sweller, 2001; Mousavi et al., 1995; Sweller, 1999; Sweller et al., 1998). Cognitive load theory posits improperly presented instructional material may impose too great a burden on working memory, subsequently leading to higher information processing load on the already limited cognitive resources of working memory (Sweller et al., 1998). Furthermore, the theory suggests that instructional design needs to be driven by an understanding of human cognition. Without knowledge of the relevant aspects of human cognitive structures and their organization into a coherent cognitive architecture, it is believed the effectiveness of instructional material is likely to suffer. Cognitive load theory has thereby been used to bridge the gap between instructional principles and knowledge of human cognition (Sweller, 2005).

Originating in the 1980s and undergoing substantial growth in later decades by researcher from around the globe (Paas, Renkl, & Sweller, 2003), CLT is grounded in aspects of human cognitive architecture and information structure to provide instructional principles best facilitating learning given the limitations of working memory (Pollock, Chandler, & Sweller, 2002). The theory has been based on a number of assumptions to include: cognitive tasks are carried out in working memory (R. M. Shiffrin & Atkinson, 1969); working memory is limited in capacity (Baddeley, 1986, 1998) and is only capable of processing a finite amount of information (i.e., chunks) at any one time (Miller, 1956); working memory is composed of both visual and auditory information processing channels (Paivio, 1990); efficiency and unlimited capacity of LTM to hold knowledge can be leveraged to overcome working memory capacity limitations (Pollock et al., 2002); schemas (e.g., Larkin, McDermott, Simon, & Simon, 1980) held in LTM, which allow multiple elements of information to be categorized as a single element (Sweller, 2005), require less working memory capacity (Pollock et al., 2002); and cognitive load can be reduced through automation, which allows schemas to be processed automatically rather than consciously (Kotovsky, Hayes, & Simon, 1985; Schneider & Shiffrin, 1977; Richard M. Shiffrin & Schneider, 1977). Cognitive load theory proposes that information should be structured to reduce preventable load on working memory (Kalyuga, Chandler, & Sweller, 1998; Sweller, 1999; Sweller et al., 1998) by developing and designing instructional material in such a way that it is processed more easily in working memory (Chandler & Sweller, 1991).

Extraneous, Intrinsic, and Germane Cognitive Load

Cognitive load theory distinguishes between three sources of cognitive load: (a) extraneous, (b) intrinsic (Pollock et al., 2002; Sweller, 2005; Sweller & Chandler, 1994; Sweller et al., 1998), and (c) germane (Sweller, 2005; Sweller et al., 1998). *Extraneous cognitive load* is caused in situations where instructional material is created using instructional design that ignores the limitations of working memory and fails to focus working memory resources on schema construction and automation (Sweller, 2005). Extraneous cognitive load is considered to be under the control of the instructional designer (Pollock et al., 2002) and is avoidable if proper instructional methods are applied. A number of CLT related studies have examined the effects of instructional methods on extraneous cognitive load (van Merrienboer & Ayres, 2005). Such effects include the use of worked examples (e.g., G. Cooper & Sweller, 1987; Kalyuga et al., 2001; Stark, Mandl, Gruber, & Renkl, 2002; Van Gerven et al., 2002), split-attention (e.g., Sweller, Chandler, Tierney, & Cooper, 1990) or the modality effect (e.g., Tindall-Ford et al., 1997), and the redundancy effect (e.g., Chandler & Sweller, 1991). Some of the effects studied by CLT yield better schema construction and a decrease in extraneous cognitive load (van Merrienboer & Ayres, 2005) when applied as principles.

For example, the goal-free effect replaces conventional problems with goal-free problems, providing learners with a nonspecific goal; reducing extraneous cognitive load by focusing the learner's attention on problem states and available operators. The worked-examples effect replaces conventional problems with worked examples, whereas the completion problem effect replaces conventional problems with completion problems. Both reduce extraneous cognitive load by focusing the learner's attention on problem states and useful solution steps. The split-attention effect has already been discussed to some degree. This effect replaces multiple sources of information with a single source, thus reducing extraneous cognitive load because learners do not need to mentally integrate multiple sources of information. The modality effect needs little explanation; this effect reduces extraneous cognitive load through using both the visual and auditory processors of working memory. Finally, the redundancy effect, replaces multimodal sources of information that are self-contained (i.e. can be understood in isolation) with a single source of information; reducing extraneous cognitive load typically caused by the unnecessary processing of redundant information (van Merrienboer & Ayres, 2005).

Intrinsic cognitive load, on the other hand, is caused by the natural complexity of the information that must be processed. Intrinsic cognitive load is not under the control of the instructional designer, but instead is determined by levels of element interactivity (Sweller, 2005). Think of an element as a single unit of information to be processed in working memory. These elements may interact with one another at different levels of complexity. For instance, some information can be learned individually, element by element (Pollock et al., 2002). Sweller (2005) has provided the example of learning nouns of a foreign language to demonstrate this idea. Each noun translation can be learned independent of other translations (e.g., the noun "cat" can be learned independently of the noun "dog"). Element interactivity in this case is low because only a limited number of elements need to be processed in working memory at any given time to learn the information. As a result, cognitive load on working memory is also low (Pollock et al., 2002; Sweller, 2005). Some information, however, cannot be learned in isolation, but instead must be learned in the context of other material. In other words, meaningfully learning of an element cannot occur without simultaneously learning other elements (Sweller, 2005). Pollock et al. (2002) have provided the example of understanding an electric circuit to demonstrate this idea. Components of a circuit may be learned in isolation of one another; however, an understanding of the entire electrical circuit cannot be achieved without simultaneously considering several components and their relations. Element interactivity in this case is high because many elements must be processed in working memory simultaneously. As a result, cognitive load on working memory is also high (Pollock et al., 2002; Sweller, 2005). To summarize intrinsic cognitive load, complex instructional material is difficult to comprehend because of the high element interactivity and the resulting heavy cognitive load it imposes on working memory (Chandler & Sweller, 1996; Marcus, Cooper, & Sweller, 1996; Sweller, 1994).

Germane cognitive load (also called *effective cognitive load*) is caused by meaningful learning resulting from schema construction and automation (Paas et al., 2003; Sweller, 2005). Like extraneous cognitive load and unlike intrinsic cognitive load, germane cognitive load is considered to be under the control of the instructional designer. Furthermore, whereas extraneous cognitive load interferes with learning, germane cognitive load enhances learning. Extraneous cognitive load can tax the limited resources of working memory; whereas in germane cognitive load, those resources are devoted to schema acquisition and automation (Paas et al., 2003).

Cognitive Load Theory Effects

As discussed, a number of major effects exist, developed from the body of research based on CLT (e.g., Paas et al., 2003; Sweller & Chandler, 1994; Sweller et al., 1998; van Merrienboer & Ayres, 2005). Although more and more CLT related studies are now investigating the effects of instructional methods on intrinsic and germane cognitive load, CLT was once used to predominately study instructional methods intended to decrease extraneous cognitive load (van Merrienboer & Ayres, 2005). For example, the goal-free, worked examples, completion problem, split-attention, modality, and redundancy effects are the most applicable in this context (van Merrienboer & Ayres, 2005). Each of these effects address a commonly used instructional method analyzed from the perspective of relevant aspects of human cognition. When applied to the creation of instructional material, the result is reduced cognitive load on working memory and increased schema construction and automation (Sweller, 2005; van Merrienboer & Ayres, 2005). With an understanding of CLT and the importance of cognitive load management in mind, attention is turned next to CTML.

Cognitive Theory of Multimedia Learning

In chapter one, an overview of CTML was given, which entailed a discussion of the three cognitive learning principles: the dual-channels assumption, the limited capacity assumption, and the active-processing assumption. It is these learning principles in which CTML is theoretically grounded. These assumptions were later elaborated upon in chapter two in the section addressing human cognition and learning and in the section addressing CLT. These sections discussed the role of working memory, the dual-processing assertion, and the importance of cognitive load management. A discussion of the basic and advanced principles composing CTML was also offered in chapter one, which spoke to a detailed matrix classifying experimental study by basic principle found in Appendix B (see page 97). The matrix displays the total number of experiments performed in support of each basic principle. Finally, the shortcomings of CTML were discussed, which organized the limitations of the theory into the four major categories, setting and content, sampling, time, and individual differences, based on the methodological issues found in the research.

This section builds upon the aforementioned prior knowledge and focuses specifically on the modality effect. Recall that the purpose of the present study is the exploration of the cognitive aging principle, studied under the milieu of the modality effect with regard to middle-aged learners. To fully appreciate the significance of the modality effect, however, an understanding of the split-attention effect must first be acquired because the modality effect derives from the split-attention phenomenon. In the next section an in-depth discussion is given on the split-attention effect, followed by an equally detailed discussion on the modality effect.

Split-attention Effect and Principle

Examined in a number CLT related studies, the *split-attention effect* is derived from the worked example effect (Sweller et al., 1998). Split-attention occurs when multiple sources of information must be mentally integrated in a simultaneous manner before meaningful learning can take place. Because multiple sources of information must be mentally integrated, extraneous cognitive load is increased, negatively impacting learning (Ayres & Sweller, 2005).

These multiple sources of information are frequently represented as pictures and accompanying text (Sweller et al., 1998; van Merrienboer & Ayres, 2005), but can also be represented as text with text, or different forms of multimedia. Since there are always at least two sources of information involved in multimedia learning environments, multimedia is very susceptible to the split-attention effect (Sweller, 2005). However, the split-attention effect can be avoided. For instance, if the instructional material is presented as a figure and text, split-attention can be circumvented by integrating the figure and text together (Sweller & Chandler, 1994). This is called the *split-attention principle*.

The common example provided by Sweller and his colleagues (see Ayres & Sweller, 2005; Sweller & Chandler, 1994; Sweller et al., 1998) has been that of geometry instruction, which typically requires the learner to examine a figure and associated text. Neither the figure nor text are intelligible in isolation, but instead need to be mentally integrated for meaningful learning to occur. This involves finding relationships between elements of the figure and text. If these relationships are not formed, meaningful learning does not occur. Geometry instruction is considered inherently complex by nature and, therefore, an amount of intrinsic cognitive load is unavoidable. However, in separating the figure and text, extraneous cognitive load is also imposed. If the split-attention principle is followed and the figure and text are incorporated together it is believed that extraneous cognitive load can be eliminated (Sweller & Chandler, 1994).

The earliest research on the split-attention effect was conducted by Tarmizi and Sweller (1988). Since then, a number of CLT related studies demonstrating the negative consequences of split-attention have followed (e.g., Chandler & Sweller, 1991, 1992; Sweller et al., 1990; Ward & Sweller, 1990) making it one of the most well-documented effects in CLT. Unfortunately, split-attention is also persuasive in that the format of instructional material is typically determined by tradition, economic factors, or the heuristic beliefs of instructional designers (Sweller, 2005). Furthermore, the use of multiple sources of information is in itself a cognitive load on working memory (Kalyuga et al., 1998). A significantly better solution is to use auditory to represent accompanying textually based information (Low & Sweller, 2005; Mayer & Moreno, 1998), or what is referred to as the modality effect.

Modality Effect and Principle

The *modality effect* derives from the split-attention effect and posits that presenting information in dual modalities (i.e., partly visual and partly auditory) spreads total induced load across the visual and auditory channels of working memory thereby reducing cognitive load (Low & Sweller, 2005; Sweller & Chandler, 1994; Sweller et al., 1998). This is important as learning novel material can be impeded due to the capacity limitations of working memory (Low & Sweller, 2005; Sweller & Chandler, 1994). The modality effect is only applicable under certain, well-documented conditions. The modality effect is relevant when both sources (i.e., visual and auditory) of information are essential to learning. Both sources must be unintelligible when in isolation requiring mental integration for meaningful learning to occur. If both sources are intelligible, the redundancy effect and respective principle should be leveraged instead (Low & Sweller, 2005).

The modality effect has been thoroughly examined in numerous studies in past decades. Some of the earliest research focused specifically on the notion of distinct, yet interrelated information processing channels in working memory for visual and auditory information (see Penney, 1989, for an in depth review). Much of the early research demonstrated that a dual mode of presenting information can result in increased performance, suggesting that there are modality specific processing resources in working memory (Low & Sweller, 2005). This, of course, is consistent with Baddeley's (1986, 1998, 2002) model of working memory and Paivio's (Clark & Paivio, 1991; Paivio, 1971, 1990) dual coding theory. Cognitive load theory leveraged this early work, which established the premise that performance can be increased by presenting information in dual rather than single modalities, to suggest that a modality effect can be obtained under occurrences of the split-attention effect (Low & Sweller, 2005).

Perhaps the most well-known study addressing split-attention and the modality effect (using CLT as the theoretical foundation) is the research conducted by Mousavi et al. (1995), who has examined presentation sequence, modality effect, and split-attention effect using geometry instruction. Their findings have shown instructional material presented in visual and auditory modes is significantly better than the same instructional material presented in a visual manner only. Their research also has enforced the idea that the benefits of multimodal material occurred irrespective of either sequential or simultaneous presented information. Similar studies would follow, examining the modality effect in the context of CLT (e.g., Jeung & Chandler, 1997; Leahy et al., 2003; Tindall-Ford et al., 1997).

Given the richness of multimedia learning environments, which can easily involve different presentation modes and sensory modalities, it should come as no surprise that the modality effect and corresponding principle are extremely relevant in the context of multimedia learning (Low & Sweller, 2005). The modality effect has been thoroughly studied by Mayer and his colleagues in 10 experiments spanning four studies (e.g., Mayer, 1998, Experiments 1 and 2; Moreno & Mayer, 1999a, Experiments 1 and 2; 2002a, Experiments 1 and 2; Moreno et al., 2001, Experiments 4a and 4b and 5a and 5b). Across all experiments, learners who received animation with concurrent narration treatments performed better on transfer tests than did learners who received the text-based treatments (Mayer, 2003). Unfortunately, none of these studies addressed age. In all cases, the same psychology subject pool at the University of California, Santa Barbara was used.

Significance of Multimedia Learning Theories

The importance of CLT and CTML to the present study cannot be overstated. These theories can help mitigate the cognitive limitations of working memory. The cognitive theory of multimedia learning plays a significant role in the present study, serving as the theoretical foundation, which is also partly founded on CLT. Furthermore, it is the home of both the cognitive aging and modality principles. In the next section, how CTML can be used as the foundation to creating sound multimedia learning environments for older learners is presented.

Cognitive Aging Decline and Proposed Compensatory Multimedia Strategies

Thus far, four views of age-related cognitive decline have been discussed; an overview of human cognition and learning has been presented including the role of working memory and the significance of the dual-processing assertion; CLT has been introduced and CTML has been presented with emphasis placed on the modality effect. With all the necessary groundwork laid, the four views of age-related cognitive decline, which has been proposed by Paas et al. (2005), are now mapped to specific CTML principles. This proposed mapping (also the work of Paas, Van Gerven, and Tabbers (2006)) establishes a bridge between age-related cognitive decline and CTML principles as possible compensatory multimedia strategies. This mapping can be found in Appendix C (see page 102), whereas a discussion of each of the four views of age-related cognitive decline mapped to CTML principles follows.

Reduced Working Memory Capacity

It has been established that working memory is limited in capacity, especially when learning novel information. The acquisition of new knowledge relies heavily on the processing and storage capabilities of working memory (Low & Sweller, 2005; Sweller & Chandler, 1994), hence novel information has the potential of overloading working memory capacity and encumbering learning (Kalyuga et al., 1999; Sweller et al., 1998). Older learners have more difficulty learning novel material than their younger counterparts. However, making use of partial autonomy for processing visual and auditory information is believed to be a way in which to address the capacity limitations of working memory. Multimedia learning, which can be coded in both the visual and auditory channels of working memory, can result in more processed information. Presenting instructional material in both visual and auditory form might be especially beneficial to older learners, prompting Paas et al. (2005) to suggest that the modality effect can be used to compensate for the reduced working memory capacity decline.

A few studies have explored the modality effect with regard to age. Constantinidou and Baker (2002) have investigated the effects of modality presentation on the verbal learning performance of younger and older learners. They found that visual presentation resulted in better learning, recall, and retrieval information than that of auditory presentation alone. (The study by Constantinidou and Baker was not performed in the context of CLT or CTML). Van Gerven et al. (2003) had found that training with worked examples presented in visual and auditory manner were more efficient than training with worked examples presented in only a visual manner. A similar study followed by Van Gerven, Paas, Van Merrienboer et al. (2006).

Paas et al. (2005) have been quick to point out that neither the Van Gerven et al. (2003) or Van Gerven, Paas, Van Merrienboer et al. (2006) studies found a proportionally greater modality effect with older learners. Although they indicate the findings are promising, they also call attention to the deficit in studies which investigate the modality effect with regard to age.

Reduced Cognitive Speed

According to Paas et al. (2005), the biggest concern with reduced processing speed is the *simultaneity mechanism*, which originates from processing speed theory (see Salthouse, 1996). The simultaneity mechanism is the failure to integrate information elements in working memory because the elements of early processing may no longer be available when elements of later processing are activated. An example is reading an abnormally long sentence. Paas et al. have put forward three multimedia strategies to compensate for this problem: (a) the presentation of visual and auditory instructional material, (b) enhanced timing, and (c) omitting redundant information.

The first strategy, *the presentation of visual and auditory instructional material*, limits the simultaneity mechanism by presenting instructional material in both a visual and auditory manner. Instructional material takes advantage of the visual and auditory channels in working memory. In doing so, this strategy enables parallel processing of information. By processing information simultaneously rather than serially, the likelihood of the simultaneity mechanism occurring is lessened. It should come as no surprise that Paas et al. (2005) have proposed that this strategy can compensate for reduced cognitive speed with the modality principle.

The second strategy, *enhanced timing*, subscribes to the same premise as the first strategy; namely that the parallel processing of information can hinder the simultaneity mechanism from occurring. Hence this strategy can compensate for reduced cognitive speed with the *temporal contiguity principle*. This principle posits learners learn more when corresponding words and pictures are presented simultaneously rather than successively (Mayer, 2005b; Mayer & Moreno, 2003).

The third strategy, *omitting redundant information*, subscribes to the premise that by eliminating irrelevant information, unnecessary delay can be precluded between two mutually dependent information elements that enter working memory, thereby decreasing the simultaneity mechanism. Paas et al. (2005) have proposed that this strategy can compensate for reduced cognitive speed with the *redundancy principle*. This principle posits learners learn more when the same material is not presented in more than one presentation mode (e.g., animation and narration versus animation, narration, and text) (Mayer, 2005b; Mayer & Moreno, 2003).

Reduced Inhibition

According to Paas et al. (2005), reduced inhibition is concerned with both the failure to suppress irrelevant information from LTM (see Hasher & Zacks, 1988) and the inability to ignore distracting stimuli in the visual field (see Hasher, Stoltzfus, Zacks, & Rypma, 1991). Paas et al. have proposed two multimedia strategies to deal with these failures: (a) omitting redundant information and (b) attention scaffolding.

The first strategy, *omitting redundant information*, tackles reduced inhibition by eliminating redundant information, thereby, preventing irrelevant information from entering working memory. This strategy can compensate for reduced inhibition with the *coherence principle*. This principle posits that learners learn more when extraneous materials are excluded (Mayer, 2005b; Mayer & Moreno, 2003). This strategy can also compensate for reduced inhibition with the redundancy principle.

The second strategy, *attention scaffolding*, deals specifically with signaling. Attention should be focused on information relevant at the moment, ignoring information which is irrelevant at that same moment. This strategy can compensate for reduced inhibition with the *signaling principle*, which posits learners learn more when signals are included to highlight the organization of essential material (Mayer, 2005b; Mayer & Moreno, 2003). Paas et al. (2005) have also included the *spatial contiguity principle* in this strategy, which posits learners learn more when corresponding words and pictures are present near one another than far apart (Mayer, 2005b; Mayer & Moreno, 2003). By minimizing the perceptual distance between interdependent information elements, the likelihood of attending to irrelevant information is reduced.

Reduced Integration

Finally, reduced integration has been described by Paas et al. (2005) as the difficulties experienced by older learners when it comes to the coordinative processing needed to manage the flow of information between interrelated processing steps and the integration of the information (Mayr & Kliegl, 1993). In examining Appendix C (see page 102), it can be seen that the corresponding CTML principles recommended with this decline strongly resemble those found with reduced cognitive speed. Paas et al. have defined four multimedia strategies used to compensate for reduced integration: (a) the presentation of visual and auditory instructional material, (b) enhanced timing, (c) enhanced layout, and (d) omitting redundant information.

The first strategy, *the presentation of visual and auditory instructional material*, assists in the assimilation of visual and auditory information, thus this strategy can compensate for reduced integration with the modality principle. The second strategy, *enhanced timing*, determines simultaneous availability, thus this strategy can compensate for reduced integration with the temporal contiguity principle. The third strategy, *enhanced layout*, might aid in the grouping of related elements and the subsequent separation of unrelated elements, thus promoting information integration. This strategy can compensate for reduced integration with the spatial contiguity principle. The last strategy, *omitting redundant information*, prevents the integration of irrelevant information into prior knowledge. The redundancy principle is best suited for this strategy to compensate for reduced integration.

Extending the Proposed Compensatory Multimedia Strategies

The aforementioned mapping proposed by Paas et al. (2005) establishes a bridge between age-related cognitive decline and CTML principles as possible compensatory multimedia strategies. Until recently, however, few CLT principles have been examined with regard to age

(Van Gerven, Paas, & Tabbers, 2006). Van Gerven, Paas, & Tabbers (2006) have subsequently augmented their own work by introducing new multimedia strategies to compensate for their four views of age-related cognitive decline. Although the original principles proposed by Paas et al. originate from CTML, their subsequent work includes additional principles predominately found in CLT. These extended compensatory multimedia strategies are briefly described.

Extending Reduced Working Memory Capacity

Reduced working memory capacity has been extended by four additional compensatory multimedia strategies: (a) worked examples instead of conventional practice problems, (b) goal-free instead of goal-specific practice problems, (c) presenting instruction in a parts-whole sequence, and (d) omitting redundant information. In the first of these extended strategies, *worked examples instead of conventional practice problems*, worked examples can be used to reduce extraneous activity in working memory. This can prove beneficial to older learners given age-related cognitive decline. Worked examples reduce extraneous cognitive load caused by weak-method problem solving and focuses learner's attention on problem states and useful solution steps (van Merrienboer & Ayres, 2005). This strategy compensates for reduced working memory capacity with the *worked example effect*.

In the second extended strategy, *goal-free instead of goal-specific practice problems*, the learner's attention should not be primarily focused on a problem's goal state. Instead, focus should be placed on different problem states and the correct actions necessary to reach a solution. This reduces extraneous cognitive load caused by relating a current problem state and attempting to reduce differences between them. This focuses learner's attention on problem states and available operators (van Merrienboer & Ayres, 2005). This strategy compensates for reduced working memory capacity with the *goal-free effect*.

In the third extended strategy, *presenting instruction in a parts-whole sequence*, presenting basic parts of instructional material (which is prefaced by relationships between these parts) has the potential of mitigating cognitive load on working memory in earlier stages of learning. It also maximizes the chances of correctly combining these parts in the future. This strategy can compensate for reduced working memory capacity with the *pre-training principle*, which posits that learners learn more when they are aware of names and behaviors of main concepts (Mayer, 2005b; Mayer & Moreno, 2003).

The last of these extended strategies, *omitting redundant information*, has already been discussed. Put simply, in leveraging the redundancy and coherence principles, irrelevant and extraneous information is prevented from entering working memory thereby maximizing the cognitive capacity of older learners.

Extending Reduced Cognitive Speed and Reduced Integration

Reduced cognitive speed has been extended by one compensatory multimedia strategy, *presenting instruction in learner-controlled segments*. This essentially deals with making instructional material self-paced. In doing so, the learner has the freedom to customize the presentation rate of the material to the learner's own needs. Van Gerven, Paas, & Tabbers (2006) have pointed out that this strategy compensates for reduced cognitive speed with the *segmentation principle*. This principle posits that more learning occurs when a lesson is presented in learner-controlled segments rather than continuous units (Mayer, 2005b; Mayer & Moreno, 2003).

Finally, reduced integration has also been extended by one compensatory multimedia strategy, *presenting instruction in a parts-whole sequence*. Similar to what was discussed in the third extended strategy of reduced working memory capacity, this approach breaks instructional material into parts. This helps older learners integrate the different parts of the instructional material in a logical and effective step-by-step manner. This strategy compensates for reduced integration with the pre-training principle.

Significance of the Proposed Compensatory Multimedia Strategies

From a theoretical standpoint, the significance of the proposed strategies stress the argument that age-related cognitive decline in working memory call for considerations in the design of multimedia learning environments. From a practical standpoint, these strategies show how principles from existing instructional theories can be leveraged in the design of multimedia learning environments catering to the cognitive needs of older learners. Consequently, the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006) has been presented. With this understanding in mind, studies contributing to the cognitive aging principle can now be discussed, as these studies are based on this line of thinking.

Studies Contributing to the Cognitive Aging Principle

Although a number of studies were found that contribute to the cognitive aging principle, only four studies are discussed (i.e., Paas et al., 2001; Van Gerven et al., 2003; Van Gerven et al., 2002; Van Gerven, Paas, Van Merrienboer et al., 2006). Each investigates a CLT effect. Studies identified, but not included in this review were eliminated for one or more of the following reasons: CLT or CTML was not the theoretical basis of the study, the study did not clearly articulate methods, the study did not clearly articulate findings, the study was not a scholarly source from a peer-reviewed journal, and/or a copy of the original study could not be obtained. No criterion was made for research design. The four studies are shown in Table 1 classified by the effects they investigated with regard to age. Following, is a synopsis of these studies and synthesized findings presented in terms of trends and issues.

Table 1

Studies Contributing to the Cognitive Aging Principle Classified by Investigated Cognitive Load Theory Effect

Study\Effect	*Modality Effect*	*Worked Example Effect*	*Goal-Free Effect*
Paas et al. (2001)			●
Van Gerven et al. (2002)		●	
Van Gerven et al. (2003)	●	●	
Van Gerven, Paas, Van Merrienboer et al. (2006)	●		

Of the CLT and CTML effects and principles proposed by Paas et al. (2005) as compensatory multimedia strategies for handling cognitive aging, only the modality effect, the worked example effect, and goal-free effect have been examined with older learners (Van Gerven, Paas, Van Merrienboer et al., 2006). For example, the study by Paas et al. (2001) (an adapted version of Sweller and Levine's (1982) maze-tracing experiments) was designed to investigate the differential effects of goal specificity on maze learning and transfer for both younger and older learners. It was found that younger learners outperformed older learners in most conditions. Both younger and older learners performed better with the goal-free format of the maze. Paas et al. (2001) had confirmed their hypotheses that the presence or absence of a specific goal would compromise or improve, respectively, older learner's performance. The study is considered a first step toward identifying instructional procedures that can compensate for age-related cognitive decline.

Shortly thereafter, Van Gerven et al. (2002) had examined the use of worked examples with younger and older learners. The study aimed at the efficiency of worked examples as a substitute for conventional practice problems in training both younger and older learners. Findings favored the use of worked examples over that of conventional problems resulting in less training time and cognitive load. It was also found that older learners took more advantage of worked examples than their younger counterparts.

Van Gerven et al. (2003) quickly followed by exploring training efficiency with multimedia-based worked examples and conventional problems with both younger and older learners. Whereas the Van Gerven et al. (2002) study had investigated the efficiency of purely visual worked examples, Van Gerven et al. (2003) had investigated the modality effect with animated worked examples in both younger and older learners, consequently incorporating a multimedia component into their study. This was accomplished by combining the modality effect (from CLT) with the contiguity effect (from CTML), making Van Gerven et al. (2003) a continuance of Van Gerven et al. (2002). Not surprisingly, findings where similar to that of Van Gerven et al. (2002) (and prior studies investigating the modality effect) favoring multimedia-based worked examples over other training formats.

Finally, the study by Van Gerven, Paas, Van Merrienboer et al. (2006) had two goals. First, the study aimed to compensate for possible age-related differences in required mental efforts by reducing the amount of extraneous cognitive load. The study investigated CLT predictions having to do with visual and auditory processing of instructional material (essentially the modality effect). Second, the study aimed at increasing germane cognitive load by varying the variability of training problems. Results had shown that the visual and auditory presented training led to lower cognitive load than visual only presented training. Furthermore, the random presentation of examples (i.e., high variability) led to higher performance than blocked presentation (i.e., low variability).

Trends and Issues

As depicted in Table 1, only Van Gerven et al. (2003) and Van Gerven, Paas, Van Merrienboer et al. (2006) have investigated the modality effect. The Van Gerven, Paas, Van Merrienboer et al. study had explicitly addressed the modality effect, showing how visual and auditory modality leads to deeper meaningful learning. The Van Gerven et al. study, on the other hand, had contributed to both the modality and worked examples effect by investigating multimedia-based worked examples and conventional problems with both younger and older learners. Although other studies exist exploring the benefits of the modality effect with older learners outside the educational research realm (e.g., Constantinidou & Baker, 2002), only the Van Gerven et al. and Van Gerven, Paas, Van Merrienboer et al. studies have investigated the modality effect with regard to age in the context of CLT.

Furthermore, findings did not show disproportionately stronger performance from older learners over their younger counterparts with regard to the modality effect. In Van Gerven et al. (2003), no difference had been found in the beneficial effect of multimedia learning between younger and older learners. Moreover, older learners in Van Gerven, Paas, Van Merrienboer et al. (2006) had not shown a strong advantage over younger learners with regard to the multimodal and random conditions. Although these findings are disappointing (with the Van Gerven, Paas, Van Merrienboer et al. showing some promise) this trend brings up an important issue, namely further research is needed to study the modality effect with regard to age (Paas et al., 2005). Both Paas et al. (2001) and Paas et al. (2005) have concluded that findings need confirmation with other CLT effects, in more realistic complex domains, and under different experimental conditions.

These four studies revolved around the context of CLT. This is the case even though the original and extended principles proposed by Paas et al. (2005) as compensatory multimedia strategies for handling cognitive aging include principles originating from CTML, such as the coherence, pre-training, and segmentation principles. The exception to this, of course, is the study by Van Gerven et al. (2003), which had combined the modality effect from CLT and the contiguity effect from CTML. In doing so, Van Gerven et al. had added a multimedia component to the study of worked examples. Although it could be argued that the modality effect is applicable to both CLT and CTML, neither Van Gerven et al. nor Van Gerven, Paas, Van Merrienboer et al. (2006) had explicitly used CTML as their theoretical base.

Finally, the four studies used either very young participants with a mean age in the teens or 20s (e.g., Paas et al., 2001, mean age = 20.2 years, SD = 3.6; Van Gerven et al., 2003, mean age = 15.98 years, SD = 0.77; Van Gerven, Paas, Van Merrienboer et al., 2006, mean age = 23.3 years, SD = 3.0), or elderly participants with a mean age in the 60s or 70s (e.g., Paas et al., 2001, mean age = 72.4 years, SD = 8.9; Van Gerven et al., 2003, mean age = 64.48 years, SD = 4.92; Van Gerven, Paas, Van Merrienboer et al., 2006, mean age = 65.1 years, SD = 4.5). With the exception of Van Gerven et al. (2002, median age = 19.5 years), who had explicitly indicated an age range of 18 to 30 years, the four studies provide no indication that middle-aged learners in their 30s, 40s, or 50s were used.

In sum, although studies contributing to the cognitive aging principle have strong implications for the design of instructional strategies that can compensate for age-related cognitive decline (Paas et al., 2001; Van Gerven et al., 2002; Van Gerven, Paas, Van

Merrienboer et al., 2006), Paas et al. (2005) have been the first to admit that initial findings are weak and the principle needs further study.

CHAPTER THREE: RESEARCH METHODS

Chapter three describes the present study methodology used to answer the research question and hypotheses posed in chapter one. This consists of a discussion of: (a) the participants and sampling methodology, (b) research design, (c) interventions, (d) instruments, (e) apparatus, (f) procedure, (g) scoring, (h) data analysis techniques, and (i) disclosure of known methodological limitations.

Participants

The participants used in the present study were sampled from the SE & IT division of a publicly held company headquartered in the northeastern part of the United States. Participants were geographically distributed throughout the nation, residing in states such as: Alabama, California, Colorado, Florida, Georgia, Illinois, Kansas, Kentucky, Maryland, Massachusetts, Missouri, New Mexico, Oklahoma, Ohio, Texas, Utah, and Washington D.C./Virginia. Three hundred and fifty-five employees were e-mailed an invitation to participate in the present study. One hundred and twenty-two employees voluntarily agreed to participate, completed all instruments (i.e., participant experience questionnaire and retention, concept, and transfer posttests). Thirty employees were further eliminated due to age or high prior knowledge in meteorology, resulting in a total of 92 participants used in the present study.

Sampling

To replicate, as closely as possible, the Mayer and Moreno (1998) study, all participants were randomly assigned into one of two groups. Half of the participants were assigned to the experimental group who received the multimedia learning treatment presented as animation with concurrent narration (AN). The other half were assigned to the comparison group who received the same treatment presented as animation with concurrent text (AT). Homogeneity was achieved between groups based on gender, age, and education level ascertained from the participant experience questionnaire. Only data collected from participants who had low prior knowledge of meteorology and who were between the ages of 30 and 59 was used.

Power

Based on the literature review of studies contributing to the cognitive aging principle, sample size ranged as low as 54 participants (e.g., Van Gerven et al., 2002) to as high as 120 (e.g., Van Gerven et al., 2003). An a-priori power test to determine estimated sample size (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted for the present study. To correctly reject a false null hypothesis (a Type II Error), a medium effect size for Case II research ($f^2 = .25$), $\alpha = .05$, and a power of .80 ($\beta = .20$) were selected for a required sample size of 128.

However, due to time and resource constraints experienced during the data collection phase, only 92 participants were acquired, resulting in a statistical power of .66. As such, the results presented in chapter four and conclusions drawn in chapter five are limited in both scope and future application.

Research Design

The present study used a two-group posttest only research design (Campbell & Stanley, 1963) to examine the effects of cognitive aging on multimedia learning as illustrated in Figure 2.

R:	O_1	X_1	O_2	O_3	O_4
R:	O_1	X_2	O_2	O_3	O_4

Figure 2. Two-group posttest only research design

The letter 'R' indicates that all participants were randomly assigned to two groups (experimental and comparison). Both groups received the participant experience questionnaire (O_1) prior to exposure to the treatments. The experimental group was exposed to the AN treatment (X_1), whereas the comparison group was exposed to the AT treatment (X_2). Upon viewing the treatments, both groups completed a retention (O_2), concept (O_3), and transfer (O_4) posttest.

Dependent and Independent Variables

The dependent variable was the measure of multimedia learning ($O_{2,}$ $O_{3,}$ and O_4) resulting from exposure to the treatments. This was tested with a retention, concept, and transfer posttest. The independent variables were the multimedia learning environments (X_1 and X_1) represented as the two treatments. A detailed description of these treatments is provided next.

Interventions

Instructional Material

The instructional material used in the present study described the formation of lightning. This material was created by Moreno (see Mayer & Moreno, 1998, Experiment 1) and adapted from text and illustrations used in previous studies (e.g., Mayer, Bove, Bryman, Mars, & Tapangco, 1996, Experiments 1, 2, and 3; Mayer, Steinhoff, Bower, & Mars, 1995, Experiments 1, 2, and 3). This material has been subsequently used in a number of CTML related experiments (e.g., Craig et al., 2002, Experiment 1; Mayer & Chandler, 2001, Experiment 1; Mayer et al., 2005, Experiment 1; Mayer et al., 2001, Experiments 1 and 2; Mayer & Massa, 2003; Mayer, Moreno, Boire, & Vagge, 1999, Experiment 1; Mayer, Sobko et al., 2003, Experiments 1 and 2;

Moreno & Mayer, 1999a, Experiments 1 and 2; 2000a, Experiment 1; 2000b, Experiments 1 and 2; 2002b, Experiment 2).

The material was composed of 16 scenes depicting major lightning formation events: "Cool moist air moves over a warmer surface and becomes heated;" "Warmed moist air near the earth's surface then rises rapidly;" "As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud;" "The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny crystals;" "Eventually, the water droplets and ice crystals become too large to be suspended by the updrafts;" "As raindroplets and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts;" "When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind people feel just before the start of rain;" "Within the cloud, the rising and falling air currents cause electrical charges to build;" "The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice;" "The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top;" "A stepped leader of negative charges moves downward in a series of steps. It nears the ground;" "A positively charged leader travels up from such objects as trees and buildings;" "The two leaders generally meet about 165-feet above the ground;" "Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright;" "As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path;" and "This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning."

Multimedia Learning Treatments

The instructional material was presented as two computer-based multimedia treatments (i.e., animations). Although the Mayer and Moreno (1998) study used 12 scene treatments, the present study used the expanded 16 scene treatments found in a number of CTML related studies (e.g., Mayer & Chandler, 2001, Experiment 1; Mayer et al., 2005, Experiment 1; Mayer et al., 2001, Experiments 1 and 2; Mayer et al., 1999, Experiment 1; Mayer, Sobko et al., 2003, Experiments 1 and 2; Moreno & Mayer, 1999a, Experiments 1 and 2; 2002b, Experiment 2). Furthermore, even though the instructional time of these treatments has varied, ranging between 140 s (e.g., Mayer & Moreno, 1998, Experiment 1) and 300 s (e.g., Moreno & Mayer, 2002b, Experiment 2), the instructional time of the two treatments used was 240 s each. Both treatments were created with the Adobe® Flash® software for use on the Apple® Macintosh® and Microsoft® Windows® operating systems. The content and animations replicated, as closely as possible, the scientific explanations of lightning formation and the animations originally used by Mayer and Moreno (1998).

The AN treatment described the major lightning formation events in spoken words at a slow rate by a male voice, whereas the AT treatment displayed the same words on screen. Treatments used the same timing. This made the AN and AT treatments identical in all respects with the exception of modality. The AN treatment was presented in visual and auditory modality, whereas the AT treatment was represented only visually. The multimodal representation of these treatments mirrored those used in experiment one of the Mayer and Moreno (1998) study. Screen shots of the AN treatment can be found in Appendix D (see page 104); whereas the AT treatment can be found in Appendix E (see page 109).

Instruments

Four data gathering instruments were used: (a) a participant experience questionnaire, (b) a retention posttest, (c) a concept posttest, and (d) a transfer posttest. These instruments measured multimedia learning resulting from exposure to the treatments. The participant experience questionnaire solicited information about the participant's age, gender, highest education level, and prior meteorology knowledge. The retention posttest asked participants to recall relevant steps in the lightning formation process. The concept posttest required participants to match correct names with corresponding lightning formation events. Finally, the transfer posttest asked participants to generate answers to questions that required applying what they had learned on the formation of lightning to new situations. Like the treatments, these posttests mirrored those used in experiment one of the Mayer and Moreno (1998) study. Each of these instruments is presented next followed by a discussion on their validity.

Participant Experience Questionnaire

The participant experience questionnaire solicited information from participants about their age, gender, highest education level, and prior knowledge of meteorology. Participants were directly asked their age, gender, and highest education level, whereas prior meteorology knowledge was assessed using a six-item knowledge checklist and a five-item self-rating. The checklist consisted of instructions to "please check the box next to the items that apply to you" followed by a list of six items: "I regularly read the weather maps in the newspaper," "I know what a cold front is," "I can distinguish between cumulous and nimbus clouds," "I know what a low-pressure system is," "I can explain what makes the wind blow," "I know what this symbol means: [symbol for cold front]," and "I know what this symbol means: [symbol for warm front]." Participants were also asked to self-rate their overall knowledge of meteorology by placing a checkmark next to one of five-items: "very little knowledge," "between very little and average knowledge," "average knowledge," "between average and very much knowledge," or "very much knowledge."

The questionnaire was used to eliminate participants with high prior knowledge of meteorology. This exclusion was based on the study by Mayer and Gallini (1990) (and subsequently Mayer and Sims (1994)), who found that learners with low prior knowledge had shown improved performance over those with high prior knowledge. Many CTML related studies have procedures to identify and preclude learners who can demonstrate a predetermined level of prior knowledge. The Mayer and Moreno (1998) study was no exception and only included low-experience learners.

Although the questionnaire used in the present study was replicated to match, as closely as possible, the original questionnaire used in the Mayer and Moreno (1998) study, there were two main differences. First, the Mayer and Moreno questionnaire solicited information concerning the participant's Scholastic Assessment Test (SAT) score to ensure homogeneity. The questionnaire used in the present study did not do so, but instead solicited the participant's gender, age, and highest education level. Second, Mayer and Moreno administered their instruments through paper-and-pencil means, unlike the present study which administered instruments electronically and online. The questionnaire used in the present study can be found in Appendix F (see page 114).

Retention Posttest

The retention posttest asked participants to recall relevant steps in the lightning formation process. The retention posttest consisted of instructions to "please explain how lightning works."

Participants were presented with a textbox wherein to enter their response and were asked not to use any additional resources to answer the question other than what they could remember from the treatment. No additional guidance was given. Furthermore, no restrictions were placed on the content entered or length of the response. The retention posttest was replicated to match, as closely as possible, the original posttest used by Mayer and Moreno (1998) and can be found in Appendix G (see page 117).

Concept Posttest

The concept posttest required participants to match correct names with corresponding lightning formation events. Participants were presented with four scenes taken from the multimedia learning treatments along with instructions to "please match the following lightning formation events by entering the corresponding letters found on the select multimedia presentation scenes in the boxes provided below." Participants were presented with textboxes wherein to enter the corresponding letters found on the scenes. Because the concept posttest was administered online, the original matching posttest approach used in the Mayer and Moreno (1998) study, which asked participants to circle lighting formation events and write a specific letter next to them, could not be replicated. Instead, a similar matching approach for electronically-based testing was employed. The concept posttest can be found in Appendix H (see page 119).

Transfer Posttest

The transfer posttest asked participants to generate answers to questions that required applying what they had learned on the formation of lightning to new situations. Four problem questions were asked: "What could you do to decrease the intensity of lightning?" "Suppose you see clouds in the sky, but no lightning. Why not?" "What does air temperature have to do with lightning?" and "What causes lightning?" A textbox was made available for each question wherein to enter a response. Participants were asked not to use any additional resources to answer the questions other than what they had learned from the multimedia learning treatment. No additional guidance was given. Furthermore, no restrictions were placed on the content entered or length of responses. The retention posttest was replicated to match, as closely as possible, the original posttest used in the Mayer and Moreno (1998) study and can be found in Appendix I (see page 122).

Validity of Instruments

Validity was tested and confirmed by expert review from both an independent instructional designer and an expert on the topic of lightning formation. Modifications were made to all four instruments based on feedback and recommendations, unless modifications deviated significantly from the original instruments used in the Mayer and Moreno (1998) study.

Apparatus

The present study was administered online and accessed via a website. With the exception of the treatments, which were developed with the Adobe® Flash® software, the website, instruments, and all related content were developed as Active Server Pages (ASP.NET) using the Microsoft® Visual Studio® 2005 integrated development environment. To partake in the study, participants were required to have a computer with soundcard and may have been asked to use headphones. A broadband Internet connection and a JavaScript™-enabled Internet browser were also required.

Procedure

Participants were notified via e-mail that they had been selected to partake in the present study. All pertinent information to participate was included in the e-mail along with how to access the website and contact information for questions (see Appendix J, page 125). The e-mail was sent on January 2, 2008 upon the start of the study. A follow-up e-mail was sent approximately two weeks later on January 14th as a reminder that the study would end on January 16th. Those who agreed to partake in the present study, by accepting the informed consent to participate (see Appendix K, page 128), were asked to complete the participant experience questionnaire at their own rate. Unlike the retention, concept, and transfer posttests, the participant experience questionnaire was not timed.

Upon completing the questionnaire, participants were randomly assigned to either the AN (experimental) or AT (comparison) group. Depending on the group assignment, participants were presented with the appropriate treatment. The AN group was given instructions to "make sure you have, and are wearing, headphones"; whereas the AT group was told "you do not need headphones for this tutorial." Both groups were asked to "click on 'continue' below when you are ready to begin." The treatments could only be viewed once. Upon viewing the treatment, participants in both groups were asked to "click on the red icon at the bottom left of the screen" to begin testing (see Appendix L, page 131).

Participants from both groups were administered the retention, concept, and transfer posttests in that order and timed at 6, 3, and 12 minutes respectively. Once time elapsed for each posttest, entered responses were automatically saved and the participant was redirected to the next posttest. Participants completing a posttest prior to time elapsing had the option of moving onto the next posttest. Upon completion of the transfer posttest, participants were thanked for their involvement, at which time the study ended. Participants could not revisit a prior posttest. Participants could choose to withdraw at any time.

Scoring

Three independent raters using scoring rubrics determined prior knowledge score and retention, concept, and transfer posttest score of each participant. The raters were not aware of the treatment condition of each participant. The scoring procedures employed were replicated to match, as closely as possible, the scoring procedures used in the Mayer and Moreno (1998) study. The scoring process to determine prior knowledge score and posttest scores is described in the following sections. A discussion of scoring reliability is also given.

Participant Experience Questionnaire

Prior knowledge score was calculated by tallying up the number of checked domain-related activities and adding that number to the checked experience level on the self-rating. One point was received for each domain-related activity checked. A point system was used for the self-rating. One point was received for "very little knowledge," two points for "between very little and average knowledge," three points for "average knowledge," four points for "between average and very much knowledge," while finally, "very much knowledge" received five points. A maximum of 11 points could be received. Those who scored greater than five points were eliminated from the study due to prior knowledge of meteorology. To ensure scoring consistency, a scoring rubric was used to score each participant experience questionnaire. The participant experience questionnaire scoring rubric can be found in Appendix M (see page 133).

Retention Posttest Score

The retention posttest score was calculated by counting the number of major idea units in response to "please explain how lightning works." One point was received for correctly stating each of the following eight ideas: "air rises," "water condenses," "water and crystals fall," "wind is dragged downward," "negative charges fall to the bottom of the cloud," "the leaders meet," "negative charges rush down," and "positive charges rush up." A point was given regardless of wording. A maximum of eight points could be received. To ensure scoring consistency, a scoring rubric was used to score each retention posttest. The retention posttest scoring rubric can be found in Appendix N (see page 136).

Concept Posttest Score

The concept posttest score was calculated by counting the number of correct letters placed next to lightning formation events. One point was received for each correct lightning formation event and letter pairing. A maximum of eight points could be received. To ensure scoring consistency, a scoring rubric was used to score each concept posttest. The concept posttest scoring rubric can be found in Appendix O (see page 138).

Transfer Posttest Score

The transfer posttest score was calculated by counting the number of major idea units in response to the four transfer problem questions. A maximum of two points could be received for each question. For question one, acceptable major idea units included "removing positive ions from the ground and reducing the temperature difference between the ocean and earth." An unacceptable major idea unit was "removing trees or tall objects from the ground." For question two, acceptable major idea units included, for example, "tops of clouds might not be high enough to freeze," and as example two, "positive and negative charges may not be at full capacity to fall." An unacceptable major idea unit was, "cloud was not a rain cloud." For question three, acceptable major idea units included, "air must be cooler than the ground" and "temperature has to be low enough for the cloud's top to freeze." An unacceptable major idea unit was, "warm air rises." Finally, for question four, acceptable major idea units included, "differences in electrical charge in the clouds" and "difference in temperature between top and bottom of the cloud." An unacceptable major idea unit was describing the animation step-by-step without specifying that the differences in charges or temperature were the actual causes. A total maximum of eight points could be received across the four questions. To ensure scoring consistency, a scoring rubric was used to score each transfer posttest. The transfer posttest scoring rubric can be found in Appendix P (see page 140).

Reliability of Scoring

Reliability was tested and confirmed by using three independent raters. These raters scored the retention, concept, and transfer posttests. The three sets of scores were then compared so that a final score could be determined. In most cases, participant posttest scores were consistent across raters. Overall agreement between the raters was almost 67% for the retention posttest, 100% for the concept posttest, and almost 64% for the transfer posttest. Modifications were made to the scoring rubrics as necessary based on inconsistencies found in the scoring. Inconsistent scores were rated a second time based on corrective actions.

Inter-rater agreement for the retention posttest ranged from $\kappa = .63$, $p < .0001$ for raters 1 and 3 to $\kappa = .71$, $p < .0001$ for raters 2 and 3, indicating a substantial level of agreement. For the concept posttest, inter-rater agreement ranged from $\kappa = 1.00$, $p < .0001$ for raters 1 and 3 to $\kappa =$

1.00, $p < .0001$ for raters 2 and 3, indicating an almost perfect level of agreement; whereas inter-rater agreement for transfer posttest ranged from $\kappa = .60$, $p < .0001$ for raters 1 and 3 to $\kappa = .68$, $p < .0001$ for raters 2 and 3, indicating a substantial level of agreement.

Data Analysis

Data collected from the questionnaire and posttests was analyzed using the Statistical Package for Social Sciences (SPSS) software. Statistical procedures included descriptive analysis and multivariate analysis of variance (MANOVA). Descriptive analysis was conducted for participant's demographics to include gender, age, and highest education level. To test the hypotheses, a MANOVA was used to explore the differences in retention of relevant steps in the process of lightning formation, choosing correct names for elements in an illustration of lightning formation, and generating answers to problems on lightning formation between participants given a multimedia learning treatment containing animation with concurrent narration and those given the same treatment containing animation with concurrent text. A critical value of .05 was used to determine statistical significance.

Limitations of Study

The present study had known methodological limitations. These are discussed in terms of external and interval validity of the study and validity and reliability of the instruments.

External and Internal Validity of Study

In terms of external validity, findings of the present study can only be generalized to individuals from the SE & IT division of a publicly held company headquartered in the northeastern part of the United States. The population was unduly distributed across gender and age because the majority of the participants were male and in their 40s. Furthermore, the population was also unduly distributed across level of education because the majority of the participants held four-year college degrees.

In terms of internal validity, a number of potential defects need to be mentioned. First, the multimedia learning treatments depicted a cause-and-effect explanation of the lightning formation process. The generalizability of the findings is, therefore, limited to cause-and-effect multimedia content. Second, since there was no compensation for involvement, it is possible that participants did not make a sufficient effort on the posttests. Third, because the present study was administered online, the testing process could not be monitored. Although the treatments and instruments were automated, timed, and instructions explicitly stated not to use any resource other than what was learned from viewing the treatments, participants may have still consulted additional resources. Thus, it may not be certain whether the scores from the retention, concept, and transfer posttests were a good representation of participant's learning attainment.

Reliability and Validity of Instruments

Although reliability was determined statistically and validity was tested by expert review, no further procedures were exercised. In the case of validity, statistical analysis rather than judgments, as in the case of the content validation used in the present study, might have proven beneficial in identifying possible instrument errors. Consequently, additional validation procedures might be examined to include criterion-related validity and construct validity.

CHAPTER FOUR: FINDINGS

Chapter four presents the analyzed results of the present study that summarizes the applicability of the modality effect to middle-aged learners in the context of multimedia learning. Statistical procedures to include descriptive analysis and a one-way MANOVA were performed to test the research hypotheses posited in chapter one. Results showed no significant differences, resulting in the failure to reject all three hypotheses. This chapter is presented in two main sections. First, an account is given of the participant's demographics and prior meteorology knowledge. Second, findings of the three research hypotheses are presented.

Participant Demographics and Prior Knowledge

The population of the present study included employees from a publicly held company headquartered in the northeastern part of the United States. All 355 employees from the SE & IT division were invited via e-mail to participate in the present study. Two hundred employees accessed the present study over a two-week period. Sixteen employees read the consent to participate, but took no further action; nine employees did not accept the informed consent to participate, explicitly choosing not to partake in the present study; fifty-three employees accepted the informed consent to participate, but did not complete one or more of the posttests; whereas the remaining 122 employees completed the questionnaire and all posttests. Of these, 30 employees were further excluded because they scored high in prior knowledge of meteorology and/or were not between 30 and 59 years of age.

Demographic information for the remaining 92 participants is presented in Table 2. In the subsequent tables, the AN group refers to the experimental group which received the animation with concurrent narration multimedia learning treatment; whereas the AT group refers to the comparison which received the animation with concurrent text multimedia learning treatment.

Table 2

Gender, Age, and Highest Education Level Composite

		Group	
		AN	*AT*
Gender	Male	28 (60.9%)	34 (73.9%)
	Female	18 (39.1%)	12 (26.1%)
Age[a]	30-39	11 (23.9%)	14 (30.4%)
	40-49	28 (60.9%)	23 (50.0%)
	50-59	7 (15.2%)	9 (19.6%)
Highest Education Level[b]	Two-year degree or less	6 (13%)	4 (8.9%)
	Four-year degree	25 (54.3%)	29 (64.4%)
	Post-graduate study or higher	15 (32.6%)	12 (26.7%)

Note. Values enclosed in parentheses represent percentages within groups. a. Age is specified in years and findings have been grouped in 10 year increments to prevent identification of participants. b. Highest education level findings have also been grouped to prevent identification. *Two-year degree or less* represents participants who never graduated high school, graduated high school, attended some college, or earned a two-year degree. *Post-graduate study or higher* represents participants who have post-graduate study without degree, earned a master's degree, or who have earned a doctorate.

As shown in Table 2, participants are equally distributed among groups in terms of their gender, age, and education level. Both groups are each randomly assigned 46 participants. Gender is composed of 62 males (67.4%) and 30 females (32.6%). Age ranges from 30 to 59, with more than half of all the participants (51) in their 40s (55.2%). Although almost all of the participants (87) hold some type of degree (95.6%), more than half of the participants (54) have a four-year degree (59.3%). Overall, participant demographic characteristics are as expected. It should be noted that one participant randomly assigned to the AT group did not report highest education level. This participant was not removed as the focus of the present study is age, not level of education.

Furthermore, participants are also equally distributed among groups in terms of their self-rating of meteorology knowledge (see Appendix Q, page 143). Most participants (33) self-rate as having between very little and average knowledge (36.3%). Less than five percent (4.4%) self-rate their meteorology knowledge as between average and very much. None of the participants self-rate as having very much knowledge. Although participants do not self-rate themselves highly in meteorology knowledge, a quarter (25%) of the participants (23) received a prior knowledge score of five points. It should be noted that one participant, randomly assigned to the AN group, did not self-rate overall knowledge of meteorology. This participant was not removed from the present study because further analysis shows the participant did not agree to any of the questions found in the six-item knowledge checklist. As a result, the participant would have scored a total of four points even if the participant had agreed to “very much knowledge” of meteorology as a self-rating, keeping the participant in the present study. With an account of the participant’s demographics and prior meteorology knowledge presented, attention is turned next to the primary hypotheses findings.

Primary Hypotheses Findings

A one-way MANOVA was conducted to determine the main effect of the multimedia learning treatment (animation with concurrent narration and animation with concurrent text) on the retention of relevant steps in the process of lightning formation, choosing correct names for elements in an illustration of lightning formation, and generating answers to problems on lightning formation represented respectively by the retention, concept, and transfer posttest scores. A critical value of .05 was used to determine statistical significance.

Results of Box's test showed that the test for homogeneity of covariance was non-significant ($F_{6,\ 58687} = 1.01$, $p = .42$) indicating that there was insufficient evidence to reject the assumption of equality of covariance. What's more, significant differences were not found among groups. Wilks' Λ of .96 was not significant ($F_{3,\ 88} = 1.12$, $p = .35$). The multivariate η^2 based on Wilks' Λ indicated that almost 4% of the multivariate variance of the retention, concept, and transfer posttest scores was associated with the group factor. This means there was no significant difference found in posttest scores between the AN group and the AT group. Table 3 contains the means and the standard deviations on the retention, concept, and transfer posttest scores for the two groups. Maximum possible score was eight points for each of the posttests.

Table 3

Mean and Standard Deviation of Retention, Concept, and Transfer Posttest Scores for Groups

	Retention Posttest Score		*Concept Posttest Score*		*Transfer Posttest Score*	
	M	*SD*	*M*	*SD*	*M*	*SD*
AN	1.43	1.772	6.33	2.339	.54	.690
AT	1.11	1.609	6.76	1.864	.39	.537

Even though no significance was found, univariate analyses of variances (ANOVAs) were conducted. This was done because the desired power was not achieved (sample size was smaller than anticipated) and to answer the three hypotheses posited in chapter one. These post-hoc findings are presented next.

Null Hypothesis I

There is no significant difference in the retention of relevant steps in the process of lightning formation (measured by retention posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

The results of the univariate ANOVA showed no significant difference in retention posttest score ($F_{1, 90} = .85$, $p = .36$) between groups, resulting in a failure to reject null hypothesis I. In addition, less than 1% of the variance in retention posttest score accounted for the differences between groups. Meaning there was no difference in the retention of relevant steps in the process of lightning formation between participants given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

Null Hypothesis II

There is no significant difference in choosing the correct names for elements in an illustration of lightning formation (measured by concept posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

The results of the univariate ANOVA showed no significant difference in concept posttest score ($F_{1, 90} = 1.00$, $p = .33$) between groups, resulting in a failure to reject null hypothesis II. In addition, only 1% of the variance in concept posttest score accounted for the differences between groups. Meaning there was no difference in choosing the correct names for elements in an illustration of lightning formation between participants given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

Null Hypothesis III

There is no significant difference in generating answers to problems on lightning formation that require applying learning to new situations (measured by transfer posttest score) between participants given a multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

The results of the univariate ANOVA showed no significant difference in transfer posttest score ($F_{1, 90} = .97$, $p = .24$) between groups, resulting in a failure to reject null hypothesis III. In addition, less than 2% of the variance in transfer posttest score accounted for the differences between groups. Meaning there was no difference in generating answers to problems on lightning formation that require applying learning to new situations between those participants given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text.

CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006) have proposed that CLT and CTML are likely to accommodate the cognitive needs of older learners, as these theories take into consideration the limitations of working memory. However, few principles emerging from either theory have been examined in the context of cognitive aging (Paas et al., 2005; Van Gerven, Paas, & Tabbers, 2006). The abundance of studies have predominately focused on the younger learner, prompting the need for further research of CLT and CTML principles with regard to age (Paas et al., 2005). The present study addressed this need, and sought to examine the applicability of the modality effect to middle-aged learners in the context of multimedia learning.

To examine the research question posited in chapter one, a two-group posttest only research design (Campbell & Stanley, 1963) was utilized, replicating the Mayer and Moreno (1998) study, which tested the applicability of the dual-processing theory of working memory to multimedia learning. Employees from the SE & IT division of a publicly held company headquartered in the northeastern part of the United States were randomly assigned to two groups (experimental and comparison). The experimental group received the animation with concurrent narration multimedia learning treatment (AN), whereas the comparison group received the same treatment with concurrent text (AT).

Three hypotheses were tested using the method described in chapter three. Findings indicate that there is no significant difference in the retention of relevant steps in the process of lightning formation, choosing the correct names for elements in an illustration of lightning formation, or generating answers to problems on lightning formation that requires applying learning to new situations between the two groups. This chapter delves into an interpretation of the findings presented in chapter four along with a discussion of the research implications, limitations of the research methods, and recommendations for future research.

Interpretation of Findings

Null Hypothesis I

Null hypothesis I posits that there is no difference in the retention of relevant steps in the process of lightning formation between those learners who are given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text. The finding shows that there is no significant difference in retention posttest mean scores between the AN and AT groups, suggesting that middle-aged learners do not remember more verbal material when it is presented as narration than when it is presented as text. This finding is in overall agreement with CLT related research contributing to the cognitive aging principle, but is in disagreement with CTML related findings showing a modality effect.

Agreement with Past Research

In general, this finding is in agreement with CLT related research contributing to the cognitive aging principle; specifically, the findings of Van Gerven et al. (2003) and Van Gerven, Paas, Van Merrienboer et al. (2006). Although these studies did not explicitly examine verbal retention, findings from both studies had shown no significant performance difference from older learners over their younger counterparts with regard to the modality effect. In Van Gerven et al., no difference had been found in the beneficial effect of multimedia learning between young and old; whereas in Van Gerven, Paas, Van Merrienboer et al., no disproportionate benefits of CLT-based instructional formats for elderly learners was found.

Disagreement with Past Research

The same, however, cannot be said for CTML related studies contributing to the modality effect. For example, the finding from testing null hypothesis I is in disagreement with the Mayer and Moreno (1998) study, which had shown consistent findings with the prediction of the dual-processing theory. A split-attention effect in which participants randomly assigned to the AN group out performed those in the AT group on retaining steps in a cause-and-effect chain (retention posttest). According to Mayer and Moreno, the split-attention effect for retention is based on the premise that participants in the AT group cannot encode as much of the verbal material as the participants in the AN group because the AN group can hold corresponding pictorial and verbal representations in working memory concurrently in separate channels. The results of experiment one had shown that participants in the AN group tended to recall more relevant idea units on the formation of lightning (M = .69, SD = .18) than the AT group (M = .52, SD = .19). Similar findings were found in experiment two, in which participants in the AN group tended to recall more relevant idea units on a car's braking system (M = .68, SD = .19) than the AT group (M = .58, SD = .21).

The finding from testing null hypothesis I is also in disagreement with other CTML related studies exploring the modality effect. For example, both experiments one and two of the Moreno and Mayer (1999a) study had revealed a modality effect in which participants performed better when visual and verbal material was presented as speech than visually as text. In experiment two, those in the narration group performed better, recalling more idea units on the formation of lightning (M = 10.67, SD = 2.82) that those in the text group (M = 8.03, SD = 3.28). Similar findings were found in the Moreno and Mayer (2002a) study with regard to agent-based multimedia games. In experiment one, those presented with verbal information in the form of speech recalled more ideas on elements from a plant library ($M = 6.84$, $SD = 1.51$) than those presented with verbal information in the form of text ($M = 5.43$, $SD = 2.01$). In experiment two, those in the narration group recalled more ideas ($M = 7.25$, $SD = 1.57$) than those in the text group ($M = 5.88$, $SD = 1.51$). Finally, the finding from testing null hypothesis I is also in disagreement with the Moreno et al. (2001) study which investigated animated pedagogical agents. In experiment four, those presented with verbal information in the form of speech recalled more ideas on elements from a plant library ($M = 8.12$, $SD = .96$) than those presented with verbal information in the form of text ($M = 7.10$, $SD = 1.70$). In experiment five, those presented with verbal information in the form of speech recalled more ideas ($M = 8.10$, $SD = .82$) than those presented with verbal information in the form of text ($M = 7.30$, $SD = 1.49$).

There are a number of possible causes which may explain the contradictory null hypothesis I finding with past CTML related findings showing a modality effect. These potential causes are shared with the findings of null hypothesis II and III and, therefore, are discussed later in this chapter.

Null Hypothesis II

Null hypothesis II posits that there is no difference in choosing the correct names for elements in an illustration of lightning formation between those learners who are given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text. The finding shows that there is no significant difference in concept posttest mean scores between the AN and AT groups, suggesting that middle-aged learners do not perform better on visual-verbal matching when verbal material is presented as narration than when it is presented as text. This finding is in overall agreement with CLT related research contributing to the cognitive aging principle, but is in disagreement with CTML related findings showing a modality effect.

Agreement with Past Research

In general, this finding is in agreement with CLT related research contributing to the cognitive aging principle; specifically, the findings of Van Gerven et al. (2003) and Van Gerven, Paas, Van Merrienboer et al. (2006). Although these studies did not explicitly examine visual-verbal matching, findings from both studies had shown no significant performance difference from older learners over their younger counterparts with regard to the modality effect. In Van Gerven et al., no difference had been found in the beneficial effect of multimedia learning between young and old; whereas in Van Gerven, Paas, Van Merrienboer et al., no disproportionate benefits of CLT-based instructional formats for elderly learners was found.

Disagreement with Past Research

The same, however, cannot be said for CTML related studies contributing to the modality effect. For example, the finding from testing null hypothesis II is in disagreement with the Mayer and Moreno (1998) study, which had shown consistent findings with the prediction of the dual-processing theory. A split-attention effect in which participants randomly assigned to the AN group out performed those in the AT group on being able to match pictures and names of parts (concept posttest). According to Mayer and Moreno, the split-attention effect for matching is based on the premise that participants in the AT group cannot build as many referential connections between corresponding pictorial and verbal material as the participants in the AN group because the AN group can hold corresponding pictorial and verbal representations in working memory concurrently in separate channels. The results of experiment one had shown that participants in the AN group tended to match more items on the formation of lightning (*M* = .87, *SD* = .16) than the AT group (*M* = .77, *SD* = .22). Similar findings were found in experiment two, in which participants in the AN group tended to match more items on a car's braking system (*M* = .80, *SD* = .26) than the AT group (*M* = .66, *SD* = .26).

The finding from testing null hypothesis II is also in disagreement with both experiments one and two of the Moreno and Mayer (1999a) study, which had revealed a modality effect in which participants performed better when visual and verbal material was presented as speech than visually as text. In experiment two, those in the narration group performed better, matching more items on the formation of lightning (*M* = 7.07, *SD* = .87) that those in the text group (*M* = 6.52, *SD* = 1.59).

There are a number of possible causes which may explain the contradictory null hypothesis II finding with past CTML related findings showing a modality effect. These potential causes are shared with the findings of null hypothesis I and III and, therefore, are discussed later in this chapter.

Null Hypothesis III

Null hypothesis III posits that there is no difference in generating answers to problems on lightning formation that require applying learning to new situations between those learners who are given the multimedia learning treatment presented as animation with concurrent narration and those given the same treatment presented as animation with concurrent text. The finding shows that there is no significant difference in transfer posttest mean scores between the AN and AT groups, suggesting that middle-aged learners do not generate more problem-solving solutions when verbal material is presented as narration than when it is presented as text. This finding is in overall agreement with CLT related research contributing to the cognitive aging principle, but is in disagreement with CTML related findings showing a modality effect.

Agreement with Past Research

In general, this finding is in agreement with CLT related research contributing to the cognitive aging principle; specifically, the findings of Van Gerven et al. (2003) and Van Gerven, Paas, Van Merrienboer et al. (2006). Findings of which had shown no significant performance difference from older learners over their younger counterparts with regard to the modality effect. In Van Gerven et al., no difference had been found in the beneficial effect of multimedia learning between young and old; whereas in Van Gerven, Paas, Van Merrienboer et al., no disproportionate benefits of CLT-based instructional formats for elderly learners was found. Gerven, Paas, Van Merrienboer et al found no main effect for modality when examining transfer performance.

Disagreement with Past Research

The same, however, cannot be said for CTML related studies contributing to the modality effect. For example, the finding from testing hypothesis III is in disagreement with the Mayer and Moreno (1998) study, which had shown consistent findings with the prediction of the dual-processing theory. A split-attention effect in which participants randomly assigned to the AN group out performed those in the AT group on being able to use what they have learned to solve problems (transfer posttest). According to Mayer and Moreno, the split-attention effect for transfer is based on the premise that participants in the AT group cannot construct a coherent mental model of the system as well as participants in the AN group because the AN group can hold corresponding pictorial and verbal representations in working memory concurrently in separate channels. The results of experiment one had shown that participants in the AN group tended to generate more solutions on the formation of lightning (*M* = .60, *SD* = .24) than the AT group (*M* = .28, *SD* = .19). Similar findings were found in experiment two, in which participants in the AN group tended to generate more solutions (*M* = .55, *SD* = .24) than the AT group (*M* = .39, *SD* = .17).

The finding from testing null hypothesis III is also in disagreement with other CTML related studies exploring the modality effect. For example, both experiments one and two of the Moreno and Mayer (1999a) study had revealed a modality effect in which participants performed better when visual and verbal material was presented as speech than visually as text. In experiment two, those in the narration group performed better, generating more solutions on the formation of lightning (*M* = 3.55, *SD* = 1.77) than those in the text group (*M* = 1.87, *SD* = 1.31). Similar findings were found in the Moreno and Mayer (2002a) study with regard to agent-based multimedia games. In experiment one, those presented with verbal information in the form of speech gave more correct answers on elements from a plant library (*M* = 36.12, *SD* = 8.34) than those presented with verbal information in the form of text (*M* = 25.57, *SD* = 8.80). In experiment two, those in the narration group gave more correct answers (*M* = 32.08, *SD* = 6.16) than those in the text group (*M* = 24.84, *SD* = 5.96).

Finally, the finding from testing null hypothesis III is also in disagreement with the Moreno et al. (2001) study which investigated animated pedagogical agents. In experiment four, those presented with verbal information in the form of speech gave more correct answers on elements from a plant library (*M* = 39.09, *SD* = 6.82) than those presented with verbal information in the form of text (*M* = 31.20, *SD* = 8.85). In experiment five, those presented with verbal information in the form of speech gave more correct answers (M = 39.95, SD = 6.35) than those presented with verbal information in the form of text (M = 28.40, SD = 8.41).

There are a number of possible causes which may explain the contradictory findings of null hypothesis III with past CTML related findings showing a modality effect. These potential causes are shared with null hypothesis I and II and are presented next.

Explanations for Inconsistent Findings

A likely explanation for the inconsistency in findings between the present study and the Mayer and Moreno (1998), Moreno and Mayer (1999a, 2002a), and Moreno et al. (2001) studies is sampling. These studies recruited college and seventh-grade students. This is a much younger sampling than the middle-aged participants recruited for the present study. Furthermore, the required sample size of 128 was not achieved, which more than likely also contributed to the present findings.

Another possible reason is that all these studies were performed in a controlled, face-to-face, laboratory setting; whereas the present study leveraged a real-world, online setting susceptible to outside influences.

A third possible reason for the inconsistency in results may be that of multimedia experience. Researchers have argued that experience may be a mediator between age and performance (Paas et al., 2005). So much so, that some age differences in performance can be eliminated by the development of compensatory skills. While they caution that not all age-related deficiencies can be prevented by intense and prolonged practice, they do argue that experience with, or expertise in a task needs to be considered as an important mediating variable. Mayer and Moreno, Moreno and Mayer, and Moreno et al. recruited students which may not have had ample experience with multimedia learning environments; unlike the participants of the present study who may have been accustomed to receiving training as online multimedia in their professional development.

Conclusions

On the whole, the findings of the present study do not support previous CTML related research showing a modality effect (e.g., Mayer, 1998, Experiments 1 and 2; Moreno & Mayer, 1999a, Experiments 1 and 2; 2002a, Experiments 1 and 2; Moreno et al., 2001, Experiments 4a and 4b and 5a and 5b), as these studies have shown an overall effect on retention, matching, and transfer with regard to cause-and-effect content yielding consistent confirmation in support of verbal material in an auditory modality. Conversely, the lack of a main effect for modality is consistent with CLT related studies contributing to the cognitive aging principle, particularly those which have investigated the modality effect (e.g., Van Gerven et al., 2003; Van Gerven, Paas, Van Merrienboer et al., 2006).

The findings of the present study suggest that the modality effect does not apply to middle-aged learners in the context of multimedia learning. That is, middle-aged learners do not attain a higher degree of meaningful learning from animation with concurrent narration (i.e., pictorial and verbal presentation mode with visual and auditory sensory modalities) than animation with concurrent printed text (i.e., pictorial presentation mode with visual sensory modality). This was evident on three different dependent measures (i.e., retention, concept, and transfer posttests).

However, the findings need to be interpreted with caution. Explanations for the inconsistent findings suggest that there may be other causes for the lack of a modality effect other than age. These causes are further elaborated upon in the research implications, limitations of research methods, and recommendations for future research presented in the subsequent sections.

Research Implications

The presents study has important theoretical and practical implications. These implications are discussed next.

Theoretical Implications

From a theoretical standpoint, the present study is the first to directly examine the modality effect with regard to cognitive aging using CTML as its theoretical base. Although past research exists which has investigated the modality effect with regard to cognitive aging, these studies have done so using CLT as their theoretical framework. The present study is also the first to have replicated an existing CTML study with middle-aged learners, subsequently contributing to the body of research on the cognitive aging principle.

Furthermore, since the findings of the present study were not in agreement with that of the findings shown in the Mayer and Moreno (1998) study (failing to show a split-attention effect with learners exposed to information in visual and verbal modalities), the findings of the present study are subsequently in disagreement with the dual-processing theory of working memory with regard to multimedia learning.

First, in accordance with the theory and Mayer and Moreno (1998), learners exposed to multimedia learning environments should learn more when words and pictures are presented in separate modalities rather than a single modality. In other words, learners should be able to select more relevant information when presented visually and auditorily, than when presented solely visually. Unlike Mayer and Moreno, who showed consistency across two experiments with this dual-processing theory analysis, the present study did not show a difference between the AN and AT groups; those in the AT group did not recall fewer idea units than those in the AN group.

Second, with regard to split-attention conditions and according to Mayer and Moreno (1998), there should not be enough resources available to build connections between words and pictures when learner's attentional resources are used to hold words and pictures in a single modality. On the contrary when words and pictures are stored in separate working memory stores, learners should be better able to devote more attentional resources to building connections. Unlike Mayer and Moreno, who showed consistency across two experiments with this dual-processing interpretation, the present study did not show a difference between the AN and AT groups; those in the AT group did not make fewer correct visual-verbal matches than those in the AN group.

While finally, with regard to split-attention conditions and according to Mayer and Moreno (1998), the ability to answer transfer questions can be hindered because an overloaded working memory resulting from content presented in a single modality reduces the ability to build mental models. On the contrary, when information is presented in separate modalities (i.e., words in auditory working memory and pictures in visual working memory) learners are better able to organize representations in each store and integrate across stores. Unlike Mayer and Moreno, who showed consistency across two experiments with this dual-processing interpretation, the present study did not show a difference between the AN and AT groups; those in the AT group did not generate fewer solutions on the transfer posttest than those in the AN group.

Generally speaking, the findings of the present study are more in line with those of CLT related research contributing to the cognitive aging principle. While such findings do not necessitate a need to reexamine the dual-processing theory, or the line of thinking by Van Gerven et al. (2000), Paas et al. (2005), and Van Gerven, Paas, and Tabbers (2006), the findings do suggest a need for further research; as other factors may play a significant role in multimedia learning.

Practical Implications

From a practical standpoint, the failure of the present study to show a modality effect with middle-aged learners should not be seen as cause to dismiss the potential cognitive benefits of the modality effect in multimedia learning environments. Instead, the findings provide additional insight with regard to the use of the modality principle in such environments intended for older learners. These findings suggest that other contributing factors, such as age, may influence the applicability of the modality principle. The present study should, therefore, serve as a call to educational researchers, practitioners, educators, trainers, and instructional designers to broaden their study of CTML principles by examining these principles with middle-aged learners. Additional research is simply needed to determine the role of cognitive aging in multimedia learning.

Limitations of Research Methods

The present study has four limitations. First and foremost, the findings cannot be generalized to all populations. The population in the present study was unduly distributed across gender, age, and level of education. The majority of the participants were male and between 40 and 49 years of age. Nearly all had a college education, with the majority holding a four-year degree. Furthermore, the sample was limited to 92 participants, likely affecting effect size and the results.

Second, participants were exposed to the experiment materials (i.e., treatments and instruments) online from their typical work setting. The use of a real-world setting, however, introduced unwanted variables typically avoidable in a laboratory-like environment. For instance, some participants noted that they had been distracted, and as a result, did not pay as close attention to the treatment as they might have. Findings were likely affected, perhaps partially explaining the very low scores on the retention and transfer posttests.

Third, the content replicated from the Mayer and Moreno (1998) study consisted of short cause-and-effect explanations on the formation of lightning. It is unclear if other genres of content, such as narrative and descriptive text, might result in similar findings. Furthermore, it is unclear if similar results might be found if other content topics were used of greater interest to the participants.

Finally, the instrumentation was replicated, matching as closely as possible, that of the Mayer and Moreno (1998) study. However, differences existed. For instance, the matching approach used by Mayer and Moreno for the concept posttest could not be replicated because the present study was administered online. Instead of asking participants to circle lightning formation events along with writing a specific letter, the present study asked participants to match lightning formation events with corresponding letters found on screenshots of the scenes. Participants may have used the letters on the scenes to their advantage allowing them to guess, partially explaining the significantly high scores ($M = 6.33$, $SD = 2.34$ for the AN group; $M = 6.76$, $SD = 1.86$ for the AT group) compared to that of the retention ($M = 1.43$, $SD = 1.77$ for the

AN group; *M* = 1.11, *SD* = 1.61 for the AT group) and transfer posttests (*M* = .54, *SD* = .69 for the AN group; *M* = .39, *SD* = .54 for the AT group).

Recommendations for Future Research

To establish the true benefits of multimedia learning for middle-aged learners, the findings of the present study reveal a need for additional investigation. Given the possible explanations for discrepancies with past research and the limitations noted, the following recommendations for future research are offered.

First, the population was unduly distributed and relatively small. A recommendation for future research is the use of a larger sample size with a much more diverse population.

Second, study in a real-world environment needs improvement. Namely, the development of better measures, as the present study did not fully control for distractions and outside influences.

Third, stricter assessment instruments and scoring rubrics need to be developed. Although measures were taken to ensure reliability of the scoring; the very low scores on the retention and transfer posttests raise a concern.

Finally, even though the present study compensated for the individual difference of high prior knowledge, the present study did not take experience into consideration. A recommendation for future research is, therefore, to explore the role of multimedia experience on multimedia learning.

Advancements in multimedia technology will more than likely continue to outpace research on their educational effectiveness. Meanwhile, learners will more than likely continue to be exposed to multimedia learning environments. The importance of CTML cannot, for that reason, be understated. CTML is a rich and fruitful area of research providing a number of empirically supported principles aiding in the design and development of multimedia learning environments. It is hoped that educational researchers, practitioners, educators, trainers, instructional designers, and others involved in the research community will see the findings of the present study as momentum for continued research and support of basic and advanced CTML principles in the context of cognitive aging.

APPENDIX A: COGNITIVE THEORY OF MULTIMEDIA LEARNING BASIC AND ADVANCED PRINCIPLES

Table A1

Basic Principles of Multimedia Learning

Principle	*Description*
Coherence principle	Learners learn more when extraneous materials are excluded.
Modality principle	Learners learn more from animation and narration rather than animation and printed text.
Multimedia principle	Learners learn more from words and pictures than from words alone.
Pre-training principle	Learners learn more when they are aware of names and behaviors of main concepts.
Personalization, voice, and image principle	Learners learn more when words of a multimedia presentation are in conversational style rather than formal style; when words are spoken in a standard-accented human voice rather than a foreign-accented voice or machine voice; but do not necessarily learn more when the speaker's image is on the screen.
Redundancy principle	Learners learn more when the same material is not presented in more than one presentation mode (e.g., animation and narration versus animation, narration, and text).
Segmentation principle	Learners learn more when a lesson is presented in learner-controlled segments rather than continuous units.
Signaling principle	Learners learn more when signals are included to highlight the organization of essential material.
Spatial contiguity principle	Learners learn more when corresponding words and pictures are present near one another than far apart.
Temporal contiguity principle	Learners learn more when corresponding words and pictures are presented simultaneously rather than successively.

Table A2

Advanced Principles of Multimedia Learning

Principle	*Description*
Animation and interactivity principles	Learners do not necessarily learn more from animation than from static diagrams.
Cognitive aging principle	Instructional design principles that effectively expand the capacity of working memory are particularly helpful for older learners.
Collaboration principle	Learners learn more when involved in collaborative online learning activities.
Guided-discovery principle	Learners learn more when guidance is incorporated into discovery-based multimedia environments.
Navigation principles	Learners learn more in a hypertext environment when appropriate navigational aids are provided.
Prior knowledge principle	Instructional principles that are effective in increasing multimedia learning for novices may have the converse effect on more expert learners.
Self-explanation principle	Learners learn more when they are encouraged to create self-explanations during learning.
Site map principle	Learners learn more in an online environment when presented with a map showing where they are in a lesson.
Worked-out example principle	Learners learn more when worked-out examples are given in initial skill learning.

APPENDIX B: COGNITIVE THEORY OF MULTIMEDIA LEARNING EXPERIMENTAL STUDY GROUPED BY BASIC PRINCIPLE MATRIX

Study\Principle	Experiment	Coherence Principle	Contiguity Principle	Modality Principle	Multimedia Principle	Pre-training Principle	Personalization, Voice, and Image Principle	Redundancy Principle	Segmentation Principle	Signaling Principle	Spatial Contiguity Principle	Temporal Contiguity Principle
Number of Experiments:		8	18	10	11	7	13	7	3	5	1	8
R. K. Atkinson et al. (2005)	1						●					
R. K. Atkinson et al. (2005)	2						●					
Mautone & Mayer (2001)	3a									●		
Mautone & Mayer (2001)	3b									●		
Mayer (1989)	1		●		●							
Mayer (1989)	2		●		●							
Mayer & Anderson (1991)	1		●									●
Mayer & Anderson (1991)	2a		●		●							●
Mayer & Anderson (1991)	2b		●		●							
Mayer & Anderson (1992)	1		●		●							●
Mayer & Anderson (1992)	2		●		●							●
Mayer & Chandler (2001)	1					●						
Mayer & Chandler (2001)	2								●			
Mayer, Dow et al. (2003)	2a								●			
Mayer, Dow et al. (2003)	2b								●			
Mayer et al. (2004)	1						●					
Mayer et al. (2004)	2						●					
Mayer et al. (2004)	3						●					

Study\Principle	Experiment	Coherence Principle	Contiguity Principle	Modality Principle	Multimedia Principle	Pre-training Principle	Personalization, Voice, and Image Principle	Redundancy Principle	Segmentation Principle	Signaling Principle	Spatial Contiguity Principle	Temporal Contiguity Principle
Mayer & Gallini (1990)	1		●		●							
Mayer & Gallini (1990)	2		●		●							
Mayer & Gallini (1990)	3		●		●							
Mayer & Jackson (2005)	1a	●										
Mayer & Jackson (2005)	1b	●										
Mayer & Jackson (2005)	2	●										
Mayer et al. (2006)	n/a						●					
Mayer et al. (2001)	1	●						●				
Mayer et al. (2001)	2							●				
Mayer et al. (2001)	3	●										
Mayer et al. (2001)	4	●										
Mayer, Mathias, & Wetzell (2002)	1					●						
Mayer, Mautone, & Prothero (2002)	1					●						
Mayer, Mautone et al. (2002)	2					●						
Mayer, Mautone et al. (2002)	3					●						
Mayer, Mathias et al. (2002)	2					●						
Mayer, Mathias et al. (2002)	3					●						

Study\Principle	Experiment	Coherence Principle	Contiguity Principle	Modality Principle	Multimedia Principle	Pre-training Principle	Personalization, Voice, and Image Principle	Redundancy Principle	Segmentation Principle	Signaling Principle	Spatial Contiguity Principle	Temporal Contiguity Principle
Mayer & Moreno (1998)	1			●								
Mayer & Moreno (1998)	2			●								
Mayer et al. (1999)	1		●									●
Mayer et al. (1999)	2		●									●
Mayer & Sims (1994)	1		●									●
Mayer & Sims (1994)	2		●									●
Mayer, Sobko et al. (2003)	1						●					
Mayer, Sobko et al. (2003)	2						●					
Mayer et al. (1995)	1		●									
Mayer et al. (1995)	2		●									
Mayer et al. (1995)	3		●									
Moreno & Mayer (1999a)	1		●	●							●	
Moreno & Mayer (1999a)	2			●								
Moreno & Mayer (1999b)	1				●							
Moreno & Mayer (2000a)	1	●										
Moreno & Mayer (2000a)	2	●										
Moreno & Mayer (2000b)	1						●					
Moreno & Mayer (2000b)	2						●					
Moreno & Mayer (2000b)	3						●					

Study\Principle	Experiment	Coherence Principle	Contiguity Principle	Modality Principle	Multimedia Principle	Pre-training Principle	Personalization, Voice, and Image Principle	Redundancy Principle	Segmentation Principle	Signaling Principle	Spatial Contiguity Principle	Temporal Contiguity Principle
Moreno & Mayer (2000b)	4						●					
Moreno & Mayer (2000b)	5						●					
Moreno & Mayer (2002a)	1			●	●			●				
Moreno & Mayer (2002a)	2			●				●				
Moreno & Mayer (2002b)	1							●				
Moreno & Mayer (2002b)	2							●				
Moreno & Mayer (2002b)	3							●				
Moreno et al. (2001)	4a			●								
Moreno et al. (2001)	4b			●								
Moreno et al. (2001)	5a			●								
Moreno et al. (2001)	5b			●								
Shah, Mayer, & Hegarty (1999)	1									●		
Shah et al. (1999)	2									●		
Shah et al. (1999)	3									●		

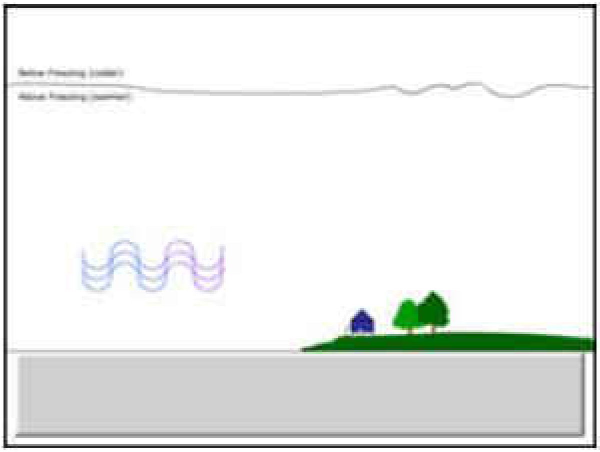
APPENDIX C: FOUR VIEWS OF COGNITIVE AGING DECLINE AND PROPOSED COMPENSATORY MULTIMEDIA STRATEGIES

Age-Related Cognitive Decline	Compensatory Multimedia Strategy	Corresponding Principle(s)
Reduced working memory capacity	Bimodal (audiovisual) presentation	Modality principle
Reduced cognitive speed	Bimodal (audiovisual) presentation	Modality principle
	Enhanced timing	Temporal contiguity principle
	Omitting redundant information	Coherence principle
		Redundancy principle
Reduced inhibition	Omitting redundant information	Coherence principle
		Redundancy principle
	Attention scaffolding	Signaling principle
		Spatial contiguity principle
Reduced integration	Bimodal (audiovisual) presentation	Modality principle
	Enhanced timing	Temporal contiguity principle
	Enhanced layout	Spatial contiguity principle
	Omitting redundant information	Coherence principle
		Redundancy principle

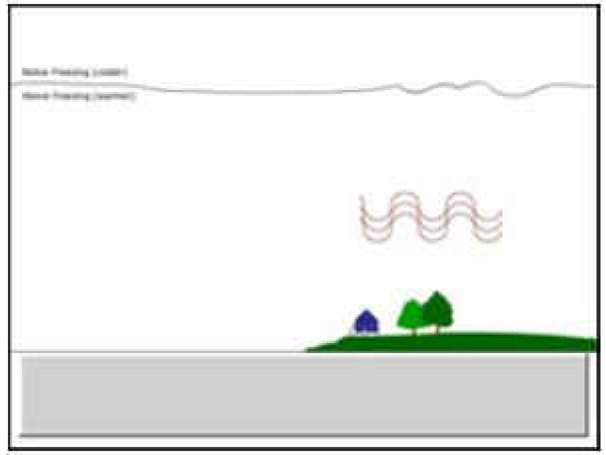
Note. Four views of cognitive aging decline directly mapped to CTML principles as possible compensatory multimedia strategies. Adapted from *The Cognitive Aging Principle in Multimedia Learning* (p. 344), by F. Paas, P. W. M. Van Gerven, & H. K. Tabbers, 2005. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 339-354). New York: Cambridge University Press. Copyright 2005 by Cambridge University Press. Reprinted with permission of the author (see Appendix R, page 145).

APPENDIX D: ANIMATION WITH NARRATION MULTIMEDIA SCENES

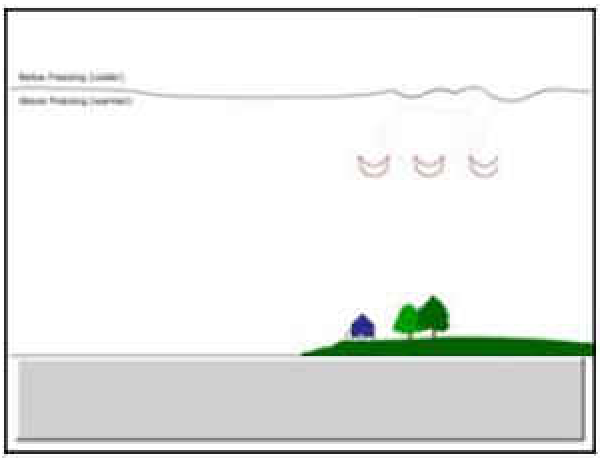
Animation with Narration Multimedia Scenes 1 through 4



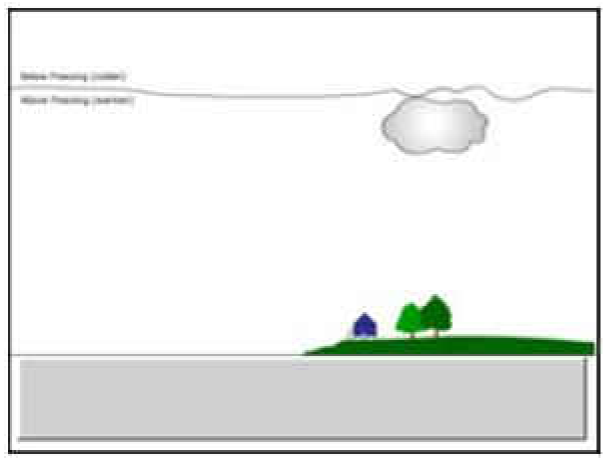
Scene 1: "Cool moist air moves over a warmer surface and becomes heated."



Scene 2: "Warmed moist air near the earth's surface then rises rapidly."

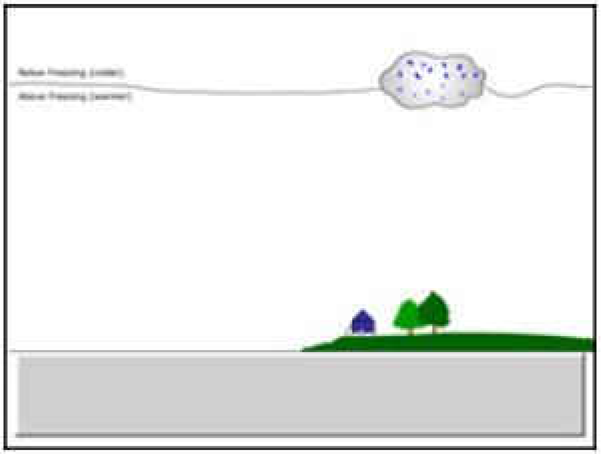


Scene 3: "As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud."

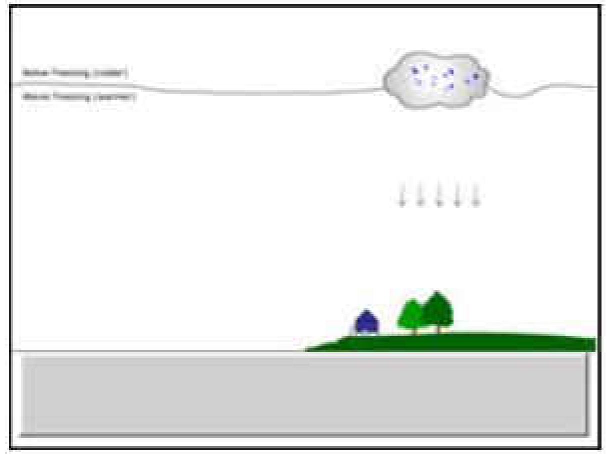


Scene 4: "The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny crystals."

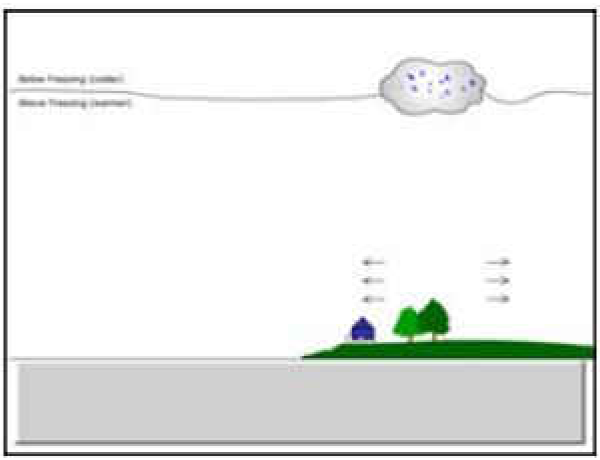
Animation with Narration Multimedia Scenes 5 through 8



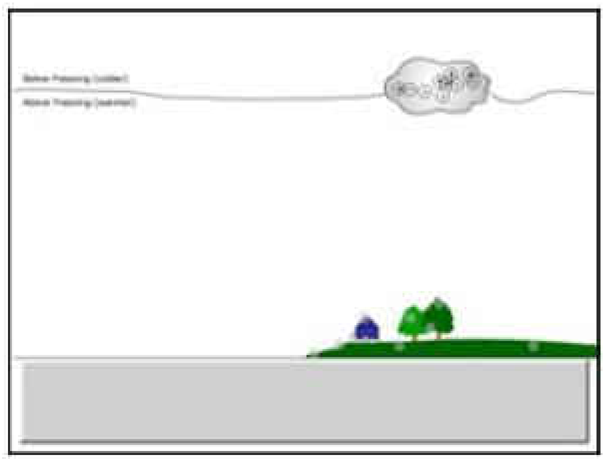
Scene 5: “Eventually, the water droplets and ice crystals become too large to be suspended by the updrafts.”



Scene 6: “As raindroplets and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts.”

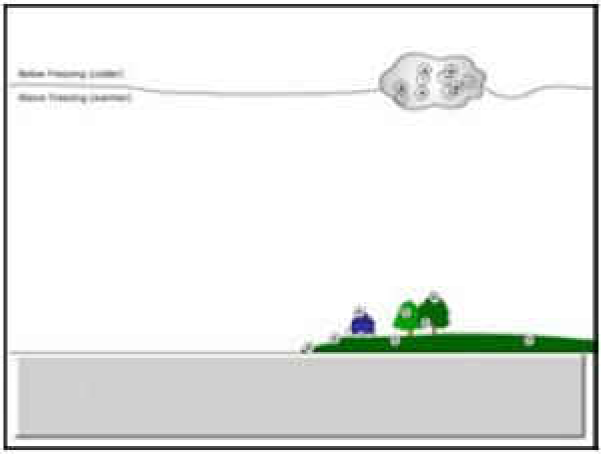


Scene 7: “When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind people feel just before the start of rain.”

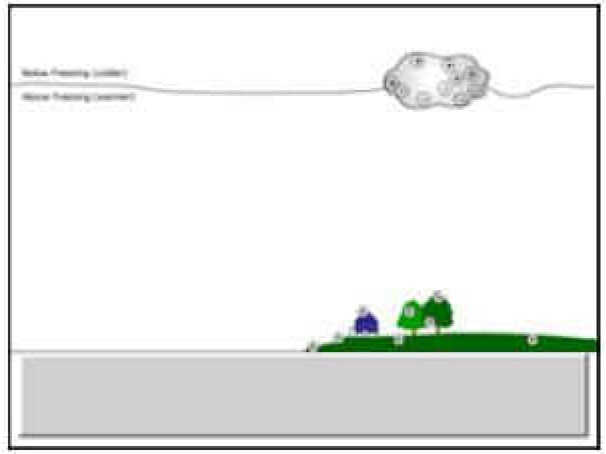


Scene 8: “Within the cloud, the rising and falling air currents cause electrical charges to build.”

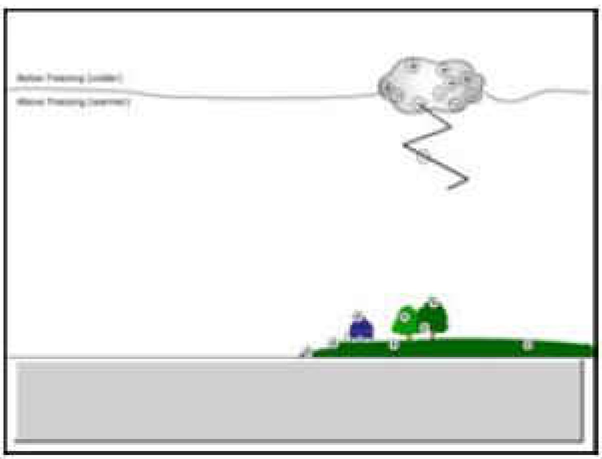
Animation with Narration Multimedia Scenes 9 through 12



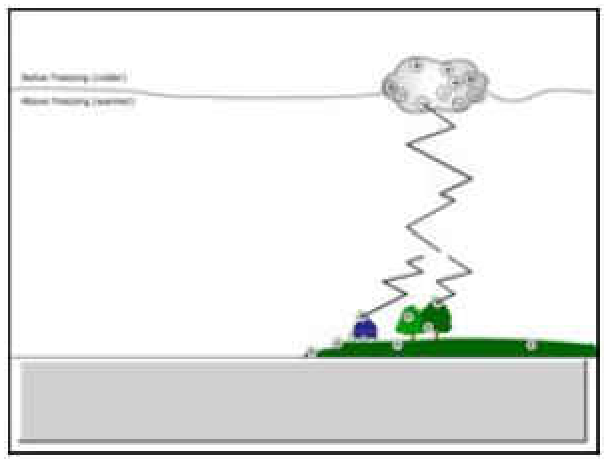
Scene 9: "The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice."



Scene 10: "The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top."

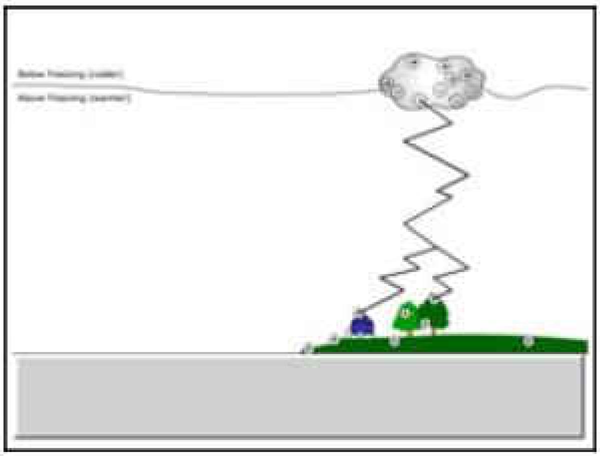


Scene 11: "A stepped leader of negative charges moves downward in a series of steps. It nears the ground."

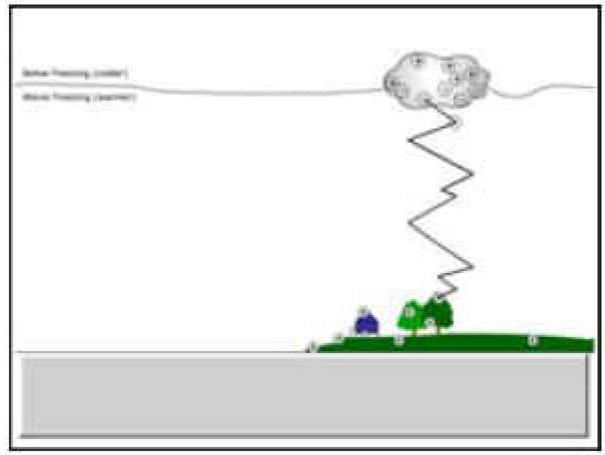


Scene 12: "A positively charged leader travels up from such objects as trees and buildings."

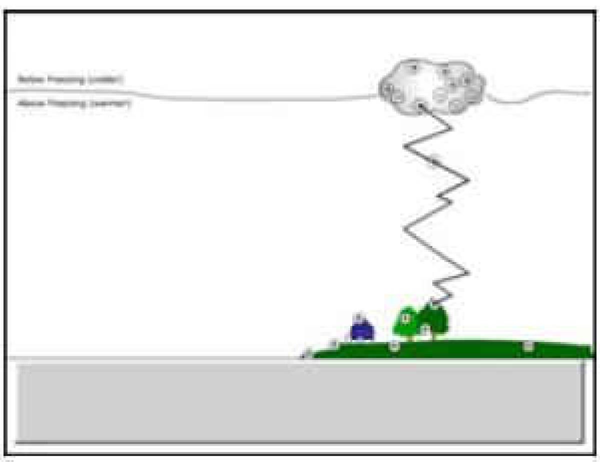
Animation with Narration Multimedia Scenes 13 through 16



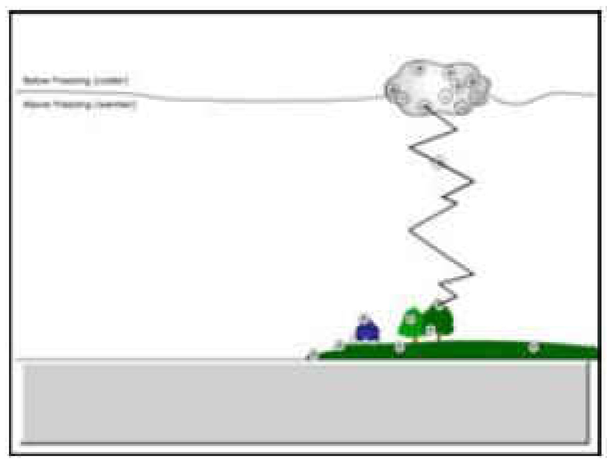
Scene 13: “The two leaders generally meet about 165-feet above the ground.”



Scene 14: “Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright.”



Scene 15: “As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path.”

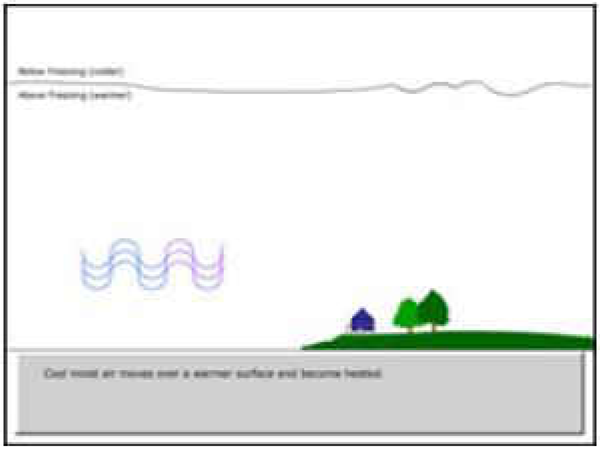


Scene 16: “This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning.”

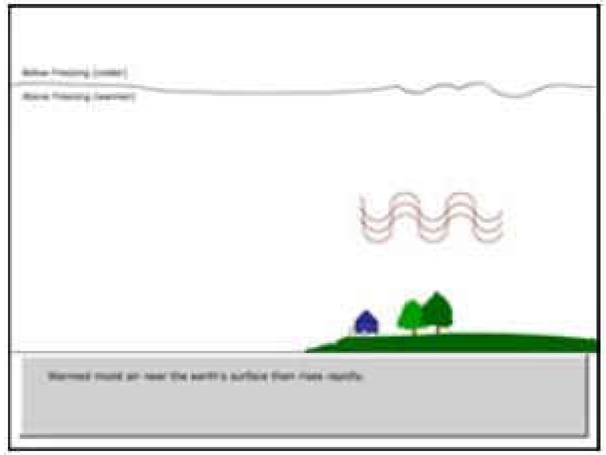
Note. Screen shots of animation with narration multimedia scenes 1 through 16 taken from multimedia learning treatment created with the Adobe® Flash® software for use on the Apple® Macintosh® and Microsoft® Windows® operating systems. By Doolittle, P. (n.d.). How Lightning Forms. Blacksburg, VA: Virginia Polytechnic Institute and State University. Used with permission of the author (see Appendix R, page 145).

APPENDIX E: ANIMATION WITH TEXT MULTIMEDIA SCENES

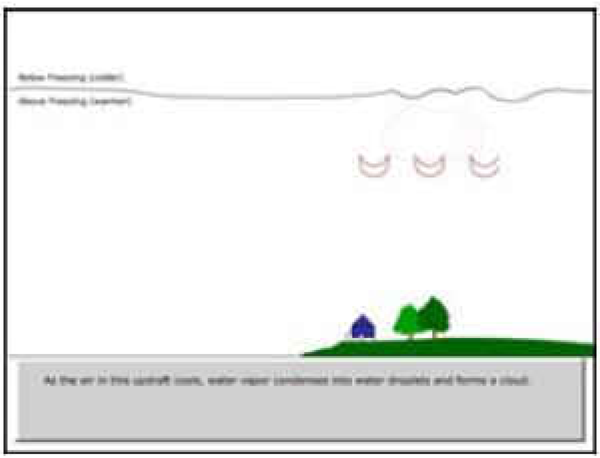
Animation with Text Multimedia Scenes 1 through 4



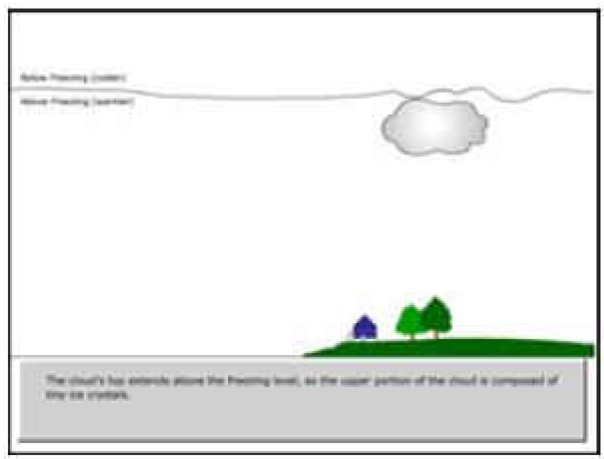
Scene 1



Scene 2

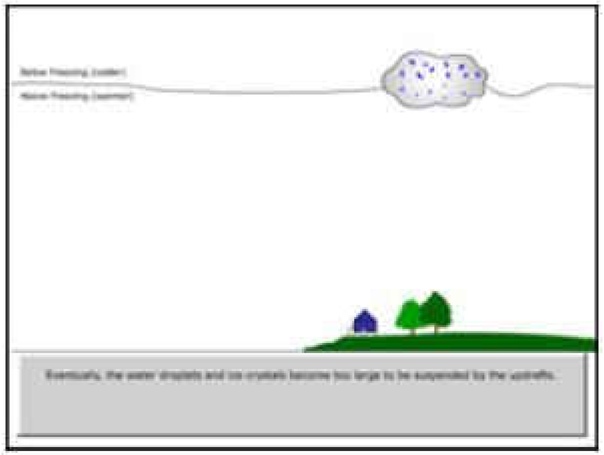


Scene 3

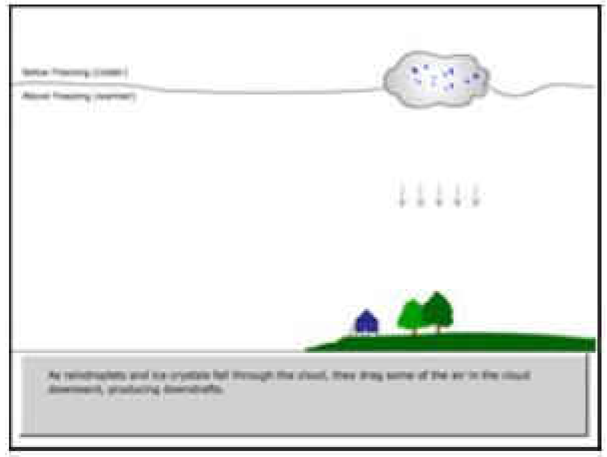


Scene 4

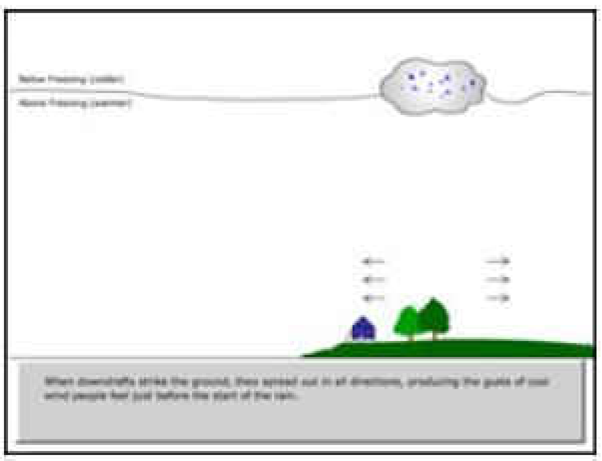
Animation with Text Multimedia Scenes 5 through 8



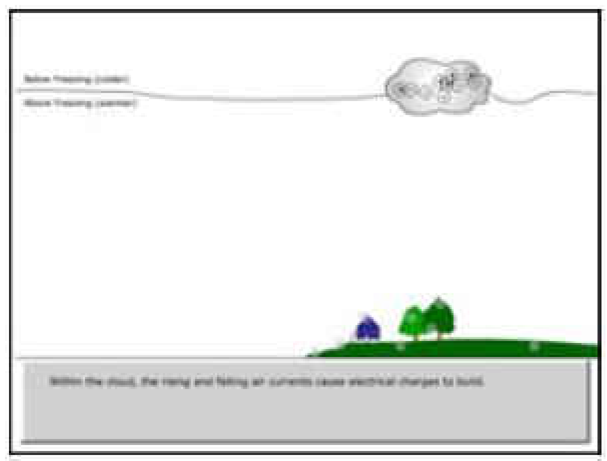
Scene 5



Scene 6

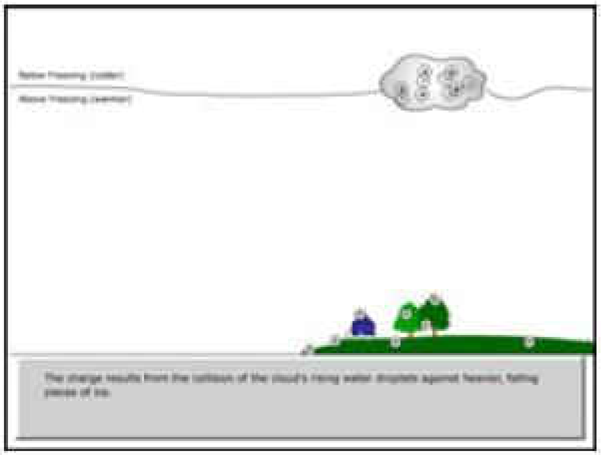


Scene 7

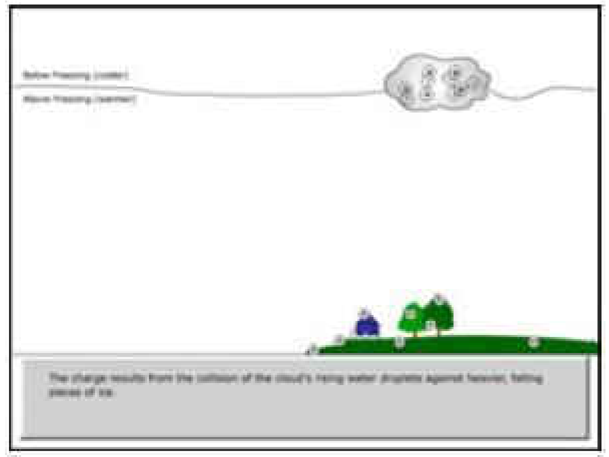


Scene 8

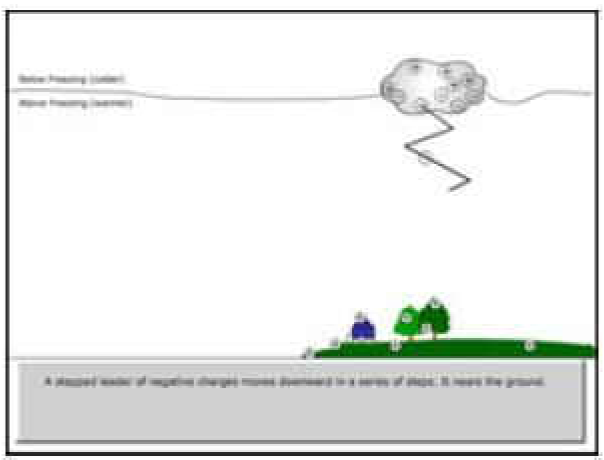
Animation with Text Multimedia Scenes 9 through 12



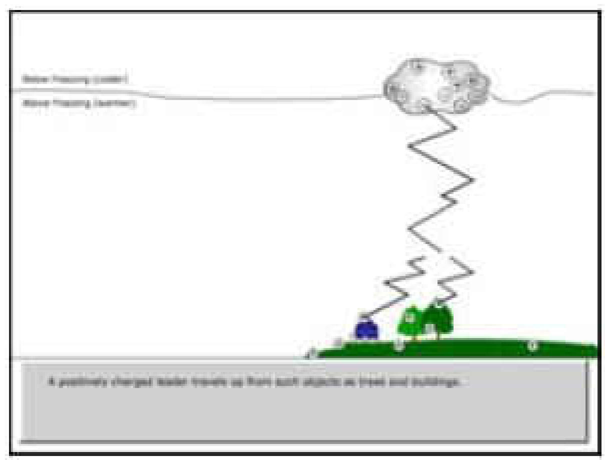
Scene 9



Scene 10

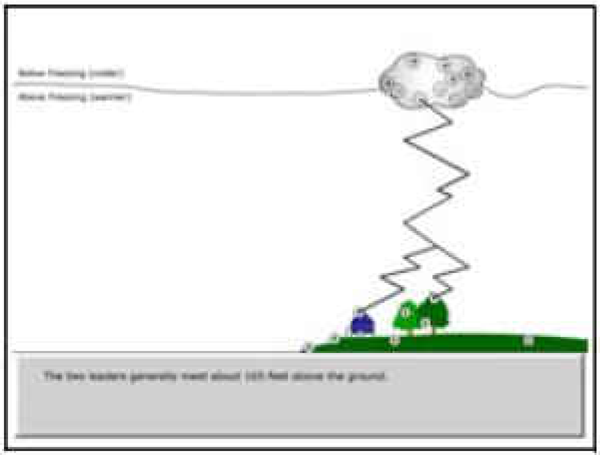


Scene 11

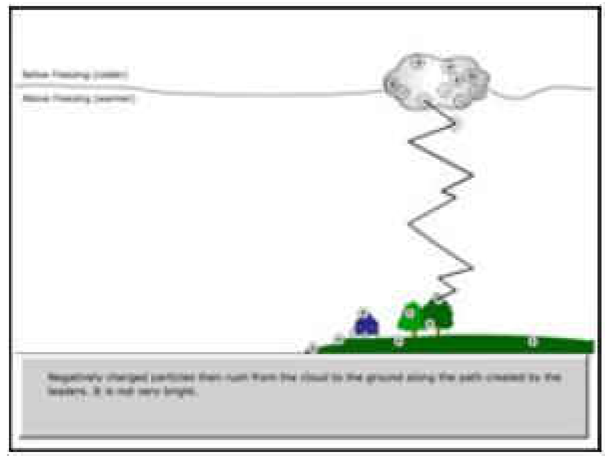


Scene 12

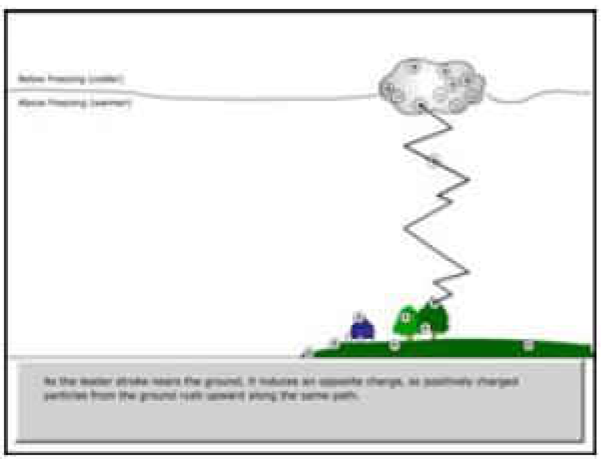
Animation with Text Multimedia Scenes 13 through 16



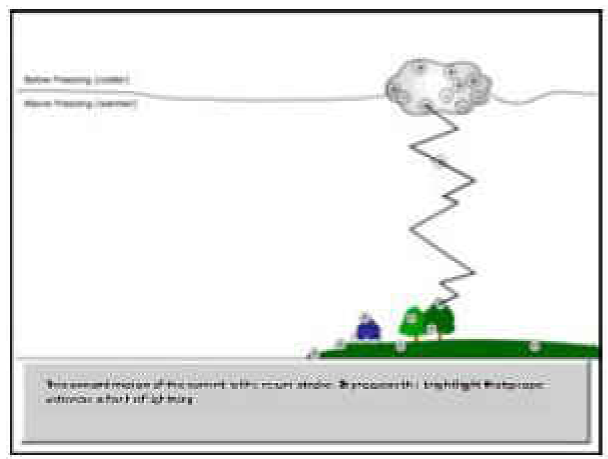
Scene 13



Scene 14



Scene 15



Scene 16

Note. Screen shots of animation with text multimedia scenes 1 through 16 taken from multimedia learning treatment created with the Adobe® Flash® software for use on the Apple® Macintosh® and Microsoft® Windows® operating systems. By Doolittle, P. (n.d.). How Lightning Forms. Blacksburg, VA: Virginia Polytechnic Institute and State University. Used with permission of the author (see Appendix R, page 145).

APPENDIX F: PARTICIPANT EXPERIENCE QUESTIONNAIRE

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

Participant Experience Questionnaire

START HERE

Instructions: Please check the box next to the items that apply to you. Otherwise, leave blank. Give the answer that <u>truly applies</u> to you and not what you would like to be true, or what you think others want to hear.

1.	I regularly read the weather maps in the newspaper.	☐
2.	I know what a cold front is.	☐
3.	I can distinguish between cumulous and nimbus clouds.	☐
4.	I know what a low-pressure system is.	☐
5.	I can explain what makes the wind blow.	☐
6.	I know what this symbol means: 	☐
7.	I know what this symbol means: 	☐

Instructions: Please rate your knowledge of meteorology (weather) by selecting one of the following:

8.	Very Little Knowledge ○	Between Very Little and Average Knowledge ○	Average Knowledge ○	Between Average and Very Much Knowledge ○	Very Much Knowledge ○

Instructions: Please answer the following questions. Press the *Next* button when you are finished. Do not use the *Back*, *Forward*, or *Refresh* buttons.

9. What is you gender?

- Male
- Female

10. What is your age? (Please enter your age in the box provided below).

11. What is your highest education level?

- Never graduated high school
- Graduated from high school
- Certification and/or Trade School
- Attended some college
- Two-year degree
- Four-year degree
- Post-graduate study without degree
- Master’s degree
- Doctoral degree
- Other

CLICK *NEXT* TO CONTINUE

Next

APPENDIX G: RETENTION POSTTEST

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

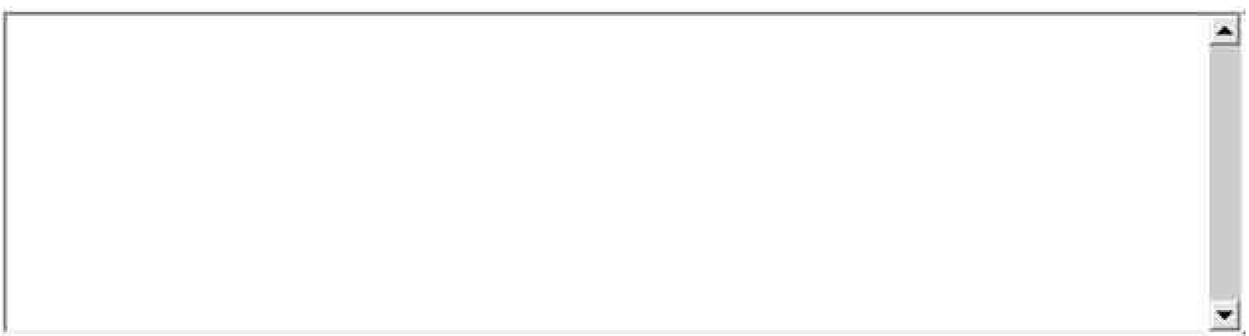
Retention Test

Time Remaining: 6 Minutes

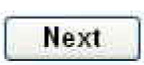
START HERE

Instructions: Please answer the following question in the box provided below. Do no use any resource to answer the question other than what you have learned from the multimedia presentation. ***You have 6 minutes to complete this test*** at which time your answers will be automatically saved and you will be presented with the next test. Press the *Next* button if you finish early. Do not use the *Back*, *Forward,* or *Refresh* buttons.

Please explain how lightning works.



CLICK *NEXT* TO CONTINUE



APPENDIX H: CONCEPT POSTTEST

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

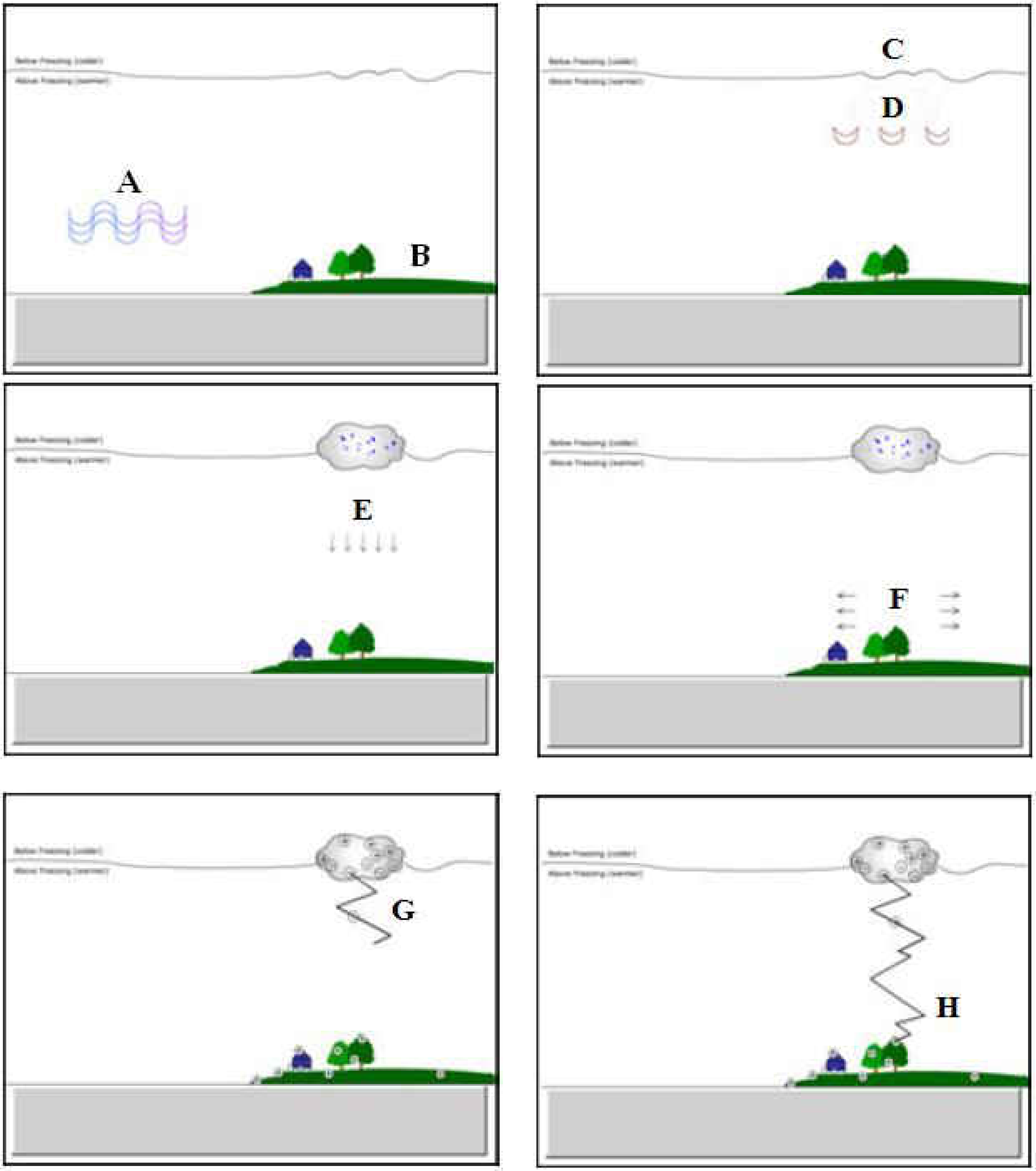
Concept Test

Time Remaining: 3 Minutes

START HERE

Instructions: Please match the following lightning formation events by entering the corresponding letters found on the select multimedia presentation scenes in the boxes provided below. ***You have 3 minutes to complete this test*** at which time your answers will be automatically saved and you will be presented with the next test. Press the *Next* button if you finish early. Do not use the *Back*, *Forward,* or *Refresh* buttons.

1.	Cool moist air	
2.	Downdraft	
3.	Freezing level	
4.	Gusts of cool wind	
5.	Stepped leader	
6.	Return Stroke	
7.	Warmer Surface	
8.	Updraft	



CLICK *NEXT* TO CONTINUE

Next

APPENDIX I: TRANSFER POSTTEST

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

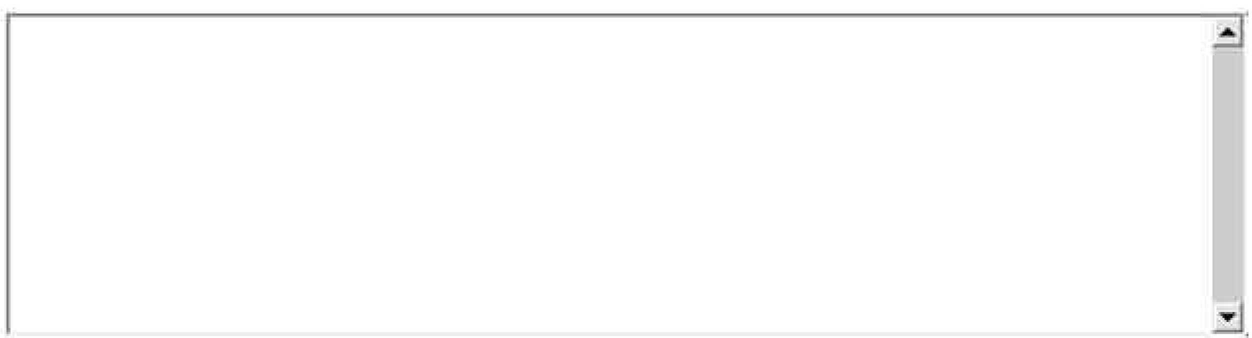
Transfer Test

Time Remaining: 12 Minutes

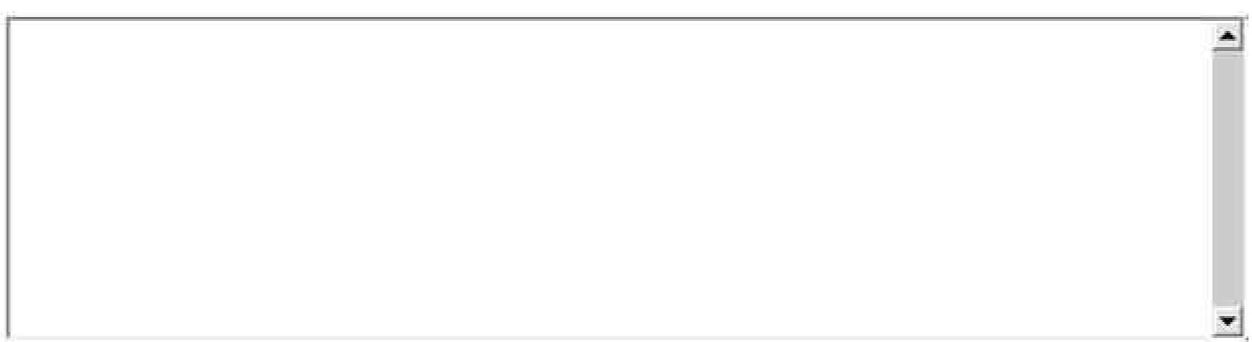
START HERE

Instructions: Please answer the following questions in the boxes provided below. Do not use any resource to answer the questions other than what you have learned during the multimedia presentation. ***You have 12 minutes to complete this test*** at which time the study will end. Press the *Next* button if you finish early. Do not use the *Back*, *Forward,* or *Refresh* buttons.

What could you do to decrease the intensity of lighting?



Suppose you see clouds in the sky, but no lightning. Why not?



What does air temperature have to do with lightning?

What causes lightning?

CLICK *NEXT* TO END STUDY

Next

APPENDIX J: RECRUITMENT E-MAIL

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

Recruitment E-Mail

A Study on the Effect of Cognitive Aging on Multimedia Learning

A research project (IRB Number: SBE-07-05344) is being conducted by Boaventura DaCosta at the University of Central Florida (UCF) to examine the effect of cognitive aging on multimedia learning. The purpose of this study is to determine if age has a significant role in meaningful learning when presented with a multimedia learning environment.

You are being asked to take part in this online study by viewing a short multimedia presentation and completing a battery of short tests. The total time required to participate in this study is approximately 25 minutes.

Please be aware that you must be 18 years of age or older to participate. Furthermore, you are not required to take part in this research and you may discontinue your participation at any time without penalty. You also may omit any item on the tests you prefer not to answer. There are no risks associated with participation in this study and there is no compensation. Furthermore, no information about you is collected for this study. You have full anonymity.

To participate, you are required to have a computer with soundcard and you may be asked to use headphones. You will need to download the Adobe® Flash® Player as well. The player is available free at: http://www.adobe.com/products/flashplayer. A broadband Internet connection and Internet browser are also required.

If you decide to participate in this study, please go to: http://---.----------------.----. Directions are provided once you access the website. You can participate in this study at anytime between January 2nd, 2008 and January 16th, 2008.

Research at UCF involving human participants is carried out under the oversight of the Institutional Review Board (IRB). Questions or concerns about research participant's rights may be directed to the UCF IRB office, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246, or by campus mail 32816-0150. The hours of operation are 8:00 am until 5:00 pm, Monday through Friday except on UCF official holidays. The telephone numbers are (407) 882-2276 and (407) 823-2901.

If you have any questions about this research, please contact Boaventura DaCosta, College of Education, at (---) -------- or --------@---.---. You may also contact his faculty advisor, Dr. Atsusi Hirumi, College of Education, at (407) 823-1760 or hirumi@mail.ucf.edu.

Thank you for your consideration and time.

Sincerely,

Boaventura DaCosta
Ph.D. Student
Instructional Systems Design
University of Central Florida

APPENDIX K: INFORMED LETTER OF CONSENT

A STUDY ON THE EFFECT OF CONGITIVE AGING ON MULTIMEDIA LEARNING

Informed Consent to Participate in a Research Study

A research project (IRB Number: SBE-07-05344) is being conducted by Boaventura DaCosta at the University of Central Florida (UCF) to examine the effect of cognitive aging on multimedia learning. The purpose of this study is to determine if age has a significant role in meaningful learning when presented with a multimedia learning environment.

You are being asked to take part in this online study by viewing a short multimedia presentation and completing a battery of short tests. The total time required to participate in this study is approximately 25 minutes. Please be aware that you must be 18 years of age or older to participate. Furthermore, you are not required to take part in this research and you may discontinue your participation at any time without penalty. You also may omit any item on the tests you prefer not to answer.

There are no risks associated with participation in this study and there is no compensation. If you have further questions about your rights, information is available from the contact listed at the end of this consent form.

Your responses will be analyzed and reported anonymously to protect your privacy. Potential benefits associated with the study include schooling learners using different multimedia pedagogies based on age. If you agree to voluntarily participate in this research project as described, please press the *Yes* button found at the end of this consent form.

Research at UCF involving human participants is carried out under the oversight of the Institutional Review Board (IRB). Questions or concerns about research participant's rights may be directed to the UCF IRB office, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246, or by campus mail 32816-0150. The hours of operation are 8:00 am until 5:00 pm, Monday through Friday except on UCF official holidays. The telephone numbers are (407) 882-2276 and (407) 823-2901.

If you have any questions about this research, please contact Boaventura DaCosta, College of Education, at (---) -------- or --------@---.---. You may also contact his faculty advisor, Dr. Atsusi Hirumi, College of Education, at (407) 823-1760 or hirumi@mail.ucf.edu.

Please print a copy of this consent form for future reference. Thank you for your participation in this research.

Sincerely,

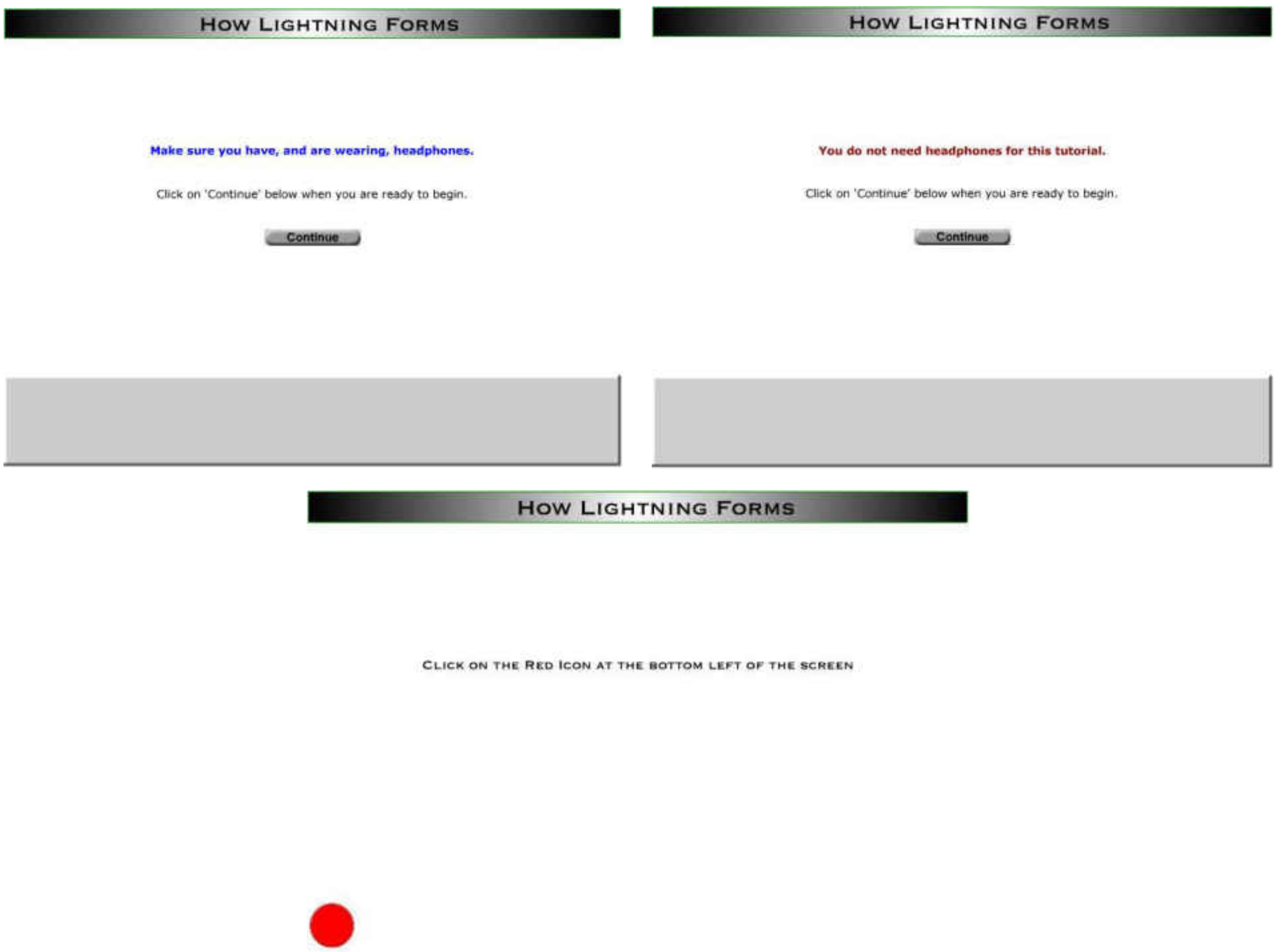
Boaventura DaCosta
Ph.D. Student
Instructional Systems Design
University of Central Florida

Do you wish to participate in the study?

Yes No

APPENDIX L: MULTIMEDIA INSTRUCTIONS

Multimedia Instructions for Animation with Narration and Animation with Text



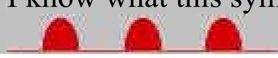
Note. Screen shots of instructions taken from multimedia learning treatment created with the Adobe® Flash® software for use on the Apple® Macintosh® and Microsoft® Windows® operating systems. By Doolittle, P. (n.d.). How Lightning Forms. Blacksburg, VA: Virginia Polytechnic Institute and State University. Used with permission of the author (see Appendix R, page 145).

APPENDIX M: PARTICIPANT EXPERIENCE QUESTIONNAIRE SCORING RUBRIC

PARTICIPANT EXPERIENCE QUESTIONNAIRE SCORING RUBRIC

Instructions: Use this rubric to calculate the score for the participant experience questionnaire. Follow the directions provided for each section below, entering the correct number in the corresponding box provided.

RATER:		RECORD NUMBER:	

	DOMAIN-RELATED ACTIVITIES	DIRECTIONS	
1.	I regularly read the weather maps in the newspaper.	If checked, enter 1 otherwise enter 0	
2.	I know what a cold front is.	If checked, enter 1 otherwise enter 0	
3.	I can distinguish between cumulous and nimbus clouds.	If checked, enter 1 otherwise enter 0	
4.	I know what a low-pressure system is.	If checked, enter 1 otherwise enter 0	
5.	I can explain what makes the wind blow.	If checked, enter 1 otherwise enter 0	
6.	I know what this symbol means: 	If checked, enter 1 otherwise enter 0	
7.	I know what this symbol means: 	If checked, enter 1 otherwise enter 0	

	SELF-RATING	DIRECTIONS	
8.	Very Little Knowledge	Enter 0	
9.	Between Very Little and Average Knowledge	If checked, enter 1 otherwise enter 0	
10	Average Knowledge	If checked, enter 2 otherwise enter 0	
11.	Between Average and Very Much Knowledge	If checked, enter 3 otherwise enter 0	
12.	Very Much Knowledge	If checked, enter 4 otherwise enter 0	

Instructions: Tally the numbers from the domain-related activities and self-rating sections, entering the final number in the Total box below. Participants who score above 5 (6 through 11) will be eliminated from the study. A maximum of 11 points can be given.

TOTAL:	

APPENDIX N: RETENTION POSTTEST SCORING RUBRIC

RETENTION POSTTEST SCORING RUBRIC

Instructions: Use this rubric to calculate the score for the retention posttest. Follow the directions provided below, entering the correct number in the corresponding box provided.

RATER:	[ ]	RECORD NUMBER:	[ ]

MAJOR IDEA UNITS FOR QUESTION "Please explain how lightning works."		DIRECTIONS	
1.	Air rises	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
2.	Water condenses	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
3.	Water and crystals fall	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
4.	Wind is dragged downward	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
5.	Negative charges fall to the bottom of the cloud	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
6.	The leaders meet	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
7.	Negative charges rush down	If stated regardless of wording, enter 1 otherwise enter 0	[ ]
8.	Positive charges rush up	If stated regardless of wording, enter 1 otherwise enter 0	[ ]

Instructions: Tally the numbers from above, entering the final number in the Total box below. A maximum of 8 points can be given.

TOTAL:	[ ]

APPENDIX O: CONCEPT POSTTEST SCORING RUBRIC

CONCEPT POSTTEST SCORING RUBRIC

Instructions: Use this rubric to calculate the score for the concept posttest. Follow the directions provided below, entering the correct number in the corresponding box provided.

RATER:		RECORD NUMBER:	

LIGHTNING FORMATION EVENTS	DIRECTIONS	
1. Cool moist air	If '**A**', enter 1 otherwise enter 0	
2. Downdraft	If '**E**', enter 1 otherwise enter 0	
3. Freezing level	If '**C**', enter 1 otherwise enter 0	
4. Gusts of cool wind	If '**F**', enter 1 otherwise enter 0	
5. Stepped leader	If '**G**', enter 1 otherwise enter 0	
6. Return Stroke	If '**H**', enter 1 otherwise enter 0	
7. Warmer Surface	If '**B**', enter 1 otherwise enter 0	
8. Updraft	If '**D**', enter 1 otherwise enter 0	

Instructions: Tally the numbers from above, entering the final number in the Total box below. A maximum of 8 points can be given.

TOTAL:	

APPENDIX P: TRANSFER POSTTEST SCORING RUBRIC

TRANSFER POSTTEST SCORING RUBRIC

Instructions: Use this rubric to calculate the score for the transfer posttest. Follow the directions provided below, entering the correct number in the corresponding box provided.

RATER:		RECORD NUMBER:	

	MAJOR IDEA UNITS FOR QUESTION "What could you do to decrease the intensity of lightning?"	DIRECTIONS	
1.	Removing positive ions from the ground	If stated regardless of wording, enter 1 otherwise enter 0	
2.	Reducing the temperature difference between the ocean and the earth	If stated regardless of wording, enter 1 otherwise enter 0	
3.	Removing trees or tall objects from the ground	If stated regardless of wording, enter 0	

	MAJOR IDEA UNITS FOR QUESTION "Suppose you see clouds in the sky, but no lightning. Why not?"	DIRECTIONS	
4.	Tops of clouds might not be high enough to freeze	If stated regardless of wording, enter 1 otherwise enter 0	
5.	Positive and negative charges might not have built up yet	If stated regardless of wording, enter 1 otherwise enter 0	
6.	Cloud was not a rain cloud	If stated regardless of wording, enter 0	

	MAJOR IDEA UNITS FOR QUESTION "What does air temperature have to do with lightning?"	DIRECTIONS	
7.	Air must be cooler than the ground	If stated regardless of wording, enter 1 otherwise enter 0	
8.	Temperature has to be low enough for the cloud's top to freeze	If stated regardless of wording, enter 1 otherwise enter 0	
9.	Warm air rises	If stated regardless of wording, enter 0	

MAJOR IDEA UNITS FOR QUESTION "What causes lightning?"		DIRECTIONS	
10.	Differences in electrical charges in the clouds	If stated regardless of wording, enter 1 otherwise enter 0	
11.	Difference in temperature between top and bottom of the cloud	If stated regardless of wording, enter 1 otherwise enter 0	
12.	Describing the animation step-by-step without specifying that the differences in charges or temperature were the actual cause	If stated regardless of wording, enter 0	

Instructions: Tally the numbers from above, entering the final number in the Total box below. A maximum of 8 points can be given.

TOTAL:	

APPENDIX Q: SELF-RATING OF METEOROLOGY KNOWLEDGE COMPOSITE

		Group	
		AN	*AT*
"I regularly read the weather maps in the newspaper."	Disagree	38 (82.6%)	39 (84.8%)
	Agree	8 (17.4%)	7 (15.2%)
"I know what a cold front is."	Disagree	31 (67.4%)	33 (71.7%)
	Agree	15 (32.6%)	13 (28.3%)
"I can distinguish between cumulous and nimbus clouds."	Disagree	34 (73.9%)	32 (69.6%)
	Agree	12 (26.1%)	14 (30.4%)
"I know what a low-pressure system is."	Disagree	34 (73.9%)	35 (76.1%)
	Agree	12 (26.1%)	11 (23.9%)
"I can explain what makes the wind blow."	Disagree	39 (84.8%)	41 (89.1%)
	Agree	7 (15.2%)	5 (10.9%)
"I know what this symbol means: [symbol for cold front]"	Disagree	33 (71.7%)	31 (67.4%)
	Agree	13 (28.3%)	15 (32.6%)
"I know what this symbol means: [symbol for warm front]"	Disagree	33 (71.7%)	32 (69.6%)
	Agree	13 (28.3%)	14 (30.4%)
Prior Knowledge	Very Little	18 (40.0%)	13 (28.3%)
	Between Very Little and Average	15 (33.3%)	18 (39.1%)
	Average	10 (22.2%)	13 (28.3%)
	Between Average and Very Much	2 (4.4%)	2 (4.3%)
Prior Knowledge Score	0	11 (23.9%)	8 (17.4%)
	1	8 (17.4%)	5 (10.9%)
	2	2 (4.3%)	6 (13.0%)
	3	3 (6.5%)	7 (15.2%)
	4	10 (21.7%)	9 (19.6%)
	5	12 (26.1%)	11 (23.9%)

Note. Values enclosed in parentheses represent percentages within groups.

APPENDIX R: COPYRIGHT RELEASES / PERMISSION LETTERS

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PERMISSION INVOICE

Inv. # P03B 14497

February 19, 2008

Boaventura DaCosta
[redacted]
Orlando, Florida
[redacted]

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Avail. Date: 5/08

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Adam Hirschberg
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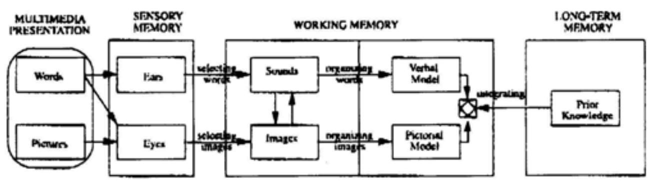
Tuesday, February 19, 2008

Boaventura DaCosta
[redacted]
Orlando, FL [redacted]

Dear Dr. Mayer,

I am completing a doctoral dissertation at the University of Central Florida entitled: "The Effect of Cognitive Aging on Multimedia Learning." I would like your permission to reprint in my dissertation your cognitive model of multimedia learning as seen here:



The model is included as Figure 1 in my dissertation and referenced in regard to an overview of the three cognitive learning principles (dual-channels, limited capacity, and active processing assumptions) composing the cognitive theory of multimedia learning.

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Sincerely,

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Boaventura DaCosta
Doctoral Student, University of Central Florida

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Doolittle, P. (n.d.). How Lightning Forms. Blacksburg, VA: Virginia Polytechnic Institute and State University.

RE: CTML: Lightning Formation Treatments | Page 1 of 1

From: Peter Doolittle [mailto:pdoo@vt.edu]
Sent: Thursday, August 23, 2007 12:05 PM
To: DaCosta . Boaventura
Subject: Re: CTML: Lightning Formation Treatments

Ben,

I'm attaching the flash files for the AN, AT, and ANT treatment conditions. They were created on a Mac, so they may not work on a PC.

What is the nature of your study?

Let me know if you need anything else.
Take care
Peter

At 10:37 AM -0400 8/23/07, DaCosta . Boaventura wrote:

Dr. DooLittle,

My name is Ben DaCosta. I'm a doctoral student at the University of Central Florida. I'm currently examining the effects of age and time in multimedia learning. In my study I'll be using the 240s/16 slide multimedia presentation on lightning formation. I'll be using both the animation with narration and animation with text versions.

While researching the instrumentation and interventions used by Mayer and his colleagues, I came across your website (http://edpsych.clahs.vt.edu/mayer/). Would it be possible to obtain copies of the Flash animations (Animation+Narration and Animation+Text) you've developed as well as written permission to use them as part of my dissertation? I would of course disclose full ownership and copyright.

Thank you for your time.

Ben DaCosta

--

Peter E. Doolittle (pdoo@vt.edu)
Department of Learning Sciences and Technology (0313)
Virginia Tech, Blacksburg, VA 24061

Executive Director, International Journal of Teaching and Learning in Higher Education
http://www.isetl.org/ijtlhe/

Director, Educational Psychology Research Program
http://edpsych.clahs.vt.edu/eprp

APPENDIX S: INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Exempt Review Status

From: **UCF Institutional Review Board**
FWA00000351, Exp. 5/07/10, IRB00001138

To: **Boaventura DaCosta**

Date: **December 14, 2007**

IRB Number: **SBE-07-05344**

Study Title: **The Effect of Cognitive Aging on Multimedia Learning**

Dear Researcher:

Your research protocol was reviewed by the IRB Vice-chair on 12/12/2007. Per federal regulations, 45 CFR 46.101, your study has been determined to be **minimal risk for human subjects and exempt** from 45 CFR 46 federal regulations and further IRB review or renewal unless you later wish to add the use of identifiers or change the protocol procedures in a way that might increase risk to participants. Before making any changes to your study, call the IRB office to discuss the changes. **A change which incorporates the use of identifiers may mean the study is no longer exempt, thus requiring the submission of a new application to change the classification to expedited if the risk is still minimal.** Please submit the Termination/Final Report form when the study has been completed. All forms may be completed and submitted online at https://iris.research.ucf.edu.

The category for which exempt status has been determined for this protocol is as follows:

3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior in which:
   (i) the human subjects are elected or appointed public officials or candidates for the public office; or
   (ii) federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

A waiver of documentation of consent has been approved for all subjects. Participants do not have to sign a consent form, but the IRB requires that you give participants a copy of the IRB-approved consent form, letter, information sheet, or statement of voluntary consent at the top of the survey.

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 12/14/2007 09:49:13 AM EST

Joanne Muratori

IRB Coordinator

LIST OF REFERENCES

Allen, P. A. (1990). Influence of processing variability on adult age differences in memory distribution of order information. *Cognitive Development, 5*, 177-192.

Allen, P. A., Madden, D. J., & Groth, K. E. (1992). Impact of age, redundancy, and perceptual noise on visual search. *Journals of Gerontology, 47*, 69-74.

Allport, D. A., Antonis, B., & Reynolds, P. (1972). On the division of attention: A disproof of the single channel hypothesis. *The Quarterly Journal of Experimental Psychology, 24*(2), 225-235.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The Psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89-195). Oxford, England: Academic Press.

Atkinson, R. K., Mayer, R. E., & Merrill, M. M. (2005). Fostering social agency in multimedia learning: Examining the impact of an animated agent's voice. *Contemporary Educational Psychology, 30*(1), 117-139.

Ayres, P., & Sweller, J. (2005). The split-attention principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 135-146). New York: Cambridge University Press.

Baddeley, A. D. (1986). *Working memory*. New York: Oxford University Press.

Baddeley, A. D. (1998). *Human memory: Theory and practice*. Boston, MA: Allyn and Bacon.

Baddeley, A. D. (2002). Is working memory still working? *European Psychologist, 7*(2), 85-97.

Brunning, R. H., Schraw, G., J., Norby, M. M., & Ronning, R. R. (2004). *Cognitive psychology and instruction*. Upper Saddle River, NJ: Pearson/Merrill/Prentice Hall.

Campbell, D. T., & Stanley, J., C. (1963). *Experimental and quasi-experimental designs for research*. Boston, MA: Houghton Mifflin Company.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 293-332.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology, 62*(2), 233-246.

Chandler, P., & Sweller, J. (1996). Cognitive load while learning to use a computer program. *Applied Cognitive Psychology, 10*, 151-170.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*(3), 149-210.

Cobb, S., & Fraser, D. S. (2005). Multimedia learning in virtual reality. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. New York: Cambridge University Press.

Constantinidou, F., & Baker, S. (2002). Stimulus modality and verbal learning performance in normal aging. *Brain and Language, 82*, 296-311.

Cooper, G., & Sweller, J. (1987). Effects of schema acquisition and rule automation on mathematical problem-solving transfer. *Journal of Educational Psychology, 79*(4), 347-362.

Cooper, H. (1998). *Synthesizing research: A guide for literature reviews (Applied social research methods)* (3rd ed. Vol. 2). Thousand Oaks, CA: Sage Publications, Inc.

Cooper, H. (2003). Editorial. *Psychological Bulletin, 129*(1), 3-9.

Cooper, H. M. (1982). Scientific guidelines for conducting integrative research reviews. *Review of Educational Research, 52*(2), 291-302.

Cooper, H. M. (1988). Organizing knowledge synthesis: A taxonomy of literature reviews. *Knowledge in Society, 1*, 104-126.

Craig, S. D., Gholson, B., & Driscoll, D. M. (2002). Animated pedagogical agents in multimedia educational environments: Effects of agent properties, picture features and redundancy. *Journal of Educational Psychology, 94*(2), 428-434.

Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191-211). New York: Plenum Press.

Craik, F. I. M., & Salthouse, T. A. (Eds.). (2000). *The handbook of aging and cognition* (2 ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. New York: Teachers College Press.

Dunsworth, Q., & Atkinson, R. K. (2007). Fostering multimedia learning of science: Exploring the role of an animated agent's image. *Computers & Education, 49*, 677-690.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191.

Fisk, J. E., & Warr, P. (1996). Age and working memory: The role of perceptual speed, the central executive, and the phonological loop. *Psychology and Aging, 11*(2), 316-323.

Frick, R. W. (1984). Using both an auditory and a visual short-term store to increase digit span. *Memory & Cognition, 12*(5), 507-514.

Gagné, R. M., Briggs, L. J., & Wager, W. W. (1992). *Principles of instructional design* (4 ed.). Fort Worth, FL: Harcourt Brace Jovanovich College Publishers.

Gellevij, M., Van Der Meij, H., De Jong, T., & Pieters, J. (2002). Multimodal versus unimodal instruction in a complex learning context. *The Journal of Experimental Education, 70*(3), 215-239.

Gilinsky, A. S., & Judd, B. B. (1994). Working memory and bias in reasoning across the life span. *Psychology and Aging, 9*(3), 356-371.

Greene, R. L. (1992). *Human memory: Paradigms and paradoxes*. Hillsdale, NJ: L. Erlbaum.

Hartley, A. A. (1992). Attention. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (Vol. 2, pp. 3-50). Mahwah, NJ: Lawrence Erlbaum Associates.

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging, 6*(4), 587-594.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(1), 163-169.

Hasher, L., & Zacks, R., T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193-225). San Diego, CA: Academic Press.

Healy, A., F., & McNamara, D., S. (1996). Verbal learning and memory: Does the modal model still work? *Annual Review of Psychology, 47*, 143-172.

Jeung, H. J., & Chandler, P. (1997). The role of visual indicators in dual sensory mode instruction. *Educational Psychology, 17*(3), 329.

Jones, D. M., Macken, W. J., & Nicholls, A. P. (2004). The phonological store of working memory: Is it phonological and is it a store? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(3), 656-674.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors, 40*(1), 1-17.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13*, 351-371.

Kalyuga, S., Chandler, P., Tuovinen, J., & Sweller, J. (2001). When problem solving is superior to studying worked examples. *Journal of Educational Psychology, 93*(3), 579-588.

Kirasic, K. C., Allen, G. L., & Haggerty, D. (1992). Age-related differences in adults' macrospatial cognitive processes. *Experimental Aging Research, 18*(1), 33-39.

Kotovsky, K., Hayes, J. R., & Simon, H. A. (1985). Why are some problems hard? Evidence from Tower of Hanoi. *Cognitive Psychology, 17*(2), 248-294.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Models of competence in solving physics problems. *Cognitive Science, 4*, 317-345.

Leahy, W., Chandler, P., & Sweller, J. (2003). When auditory presentations should and should not be a component of multimedia instruction. *Applied Cognitive Psychology, 17*, 401-418.

Light, L. L., Zelinski, E. M., & Moore, M. (1982). Adult age differences in reasoning from new information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*(5), 435-447.

Lipman, P. D., & Caplan, L. J. (1992). Adult age differences in memory for routes: Effects of instruction and spatial diagram. *Psychology and Aging, 7*(3), 435-442.

Low, R., & Sweller, J. (2005). The modality principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 147-158). New York: Cambridge University Press.

MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: Comment on Just and Carpenter (1992) and Waters and Caplan (1996). *Psychological Review, 109*(1), 35-54.

Madden, D. J., Connelly, S. L., & Pierce, T. W. (1994). Adult age differences in shifting focused attention. *Psychology and Aging, 9*(4), 528-538.

Marcus, N., Cooper, M., & Sweller, J. (1996). Understanding instructions. *Journal of Educational Psychology, 88*(1), 49-63.

Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2), 377-389.

Mayer, R. E. (1989). Systematic thinking fostered by illustrations in scientific text. *Journal of Educational Psychology, 81*(2), 240-246.

Mayer, R. E. (1996). Learning strategies for making sense out of expository text: The SOI model for guiding three cognitive processes in knowledge construction. *Educational Psychology Review, 8*(4), 357-371.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist, 32*(1), 1-19.

Mayer, R. E. (1998). *The promise of educational psychology: Learning in the content areas.* (Vol. 1). Upper Saddle River, N.J.: Prentice Hall.

Mayer, R. E. (2001). *Multimedia learning*. New York: Cambridge University Press.

Mayer, R. E. (2002). Rote versus meaningful learning. *Theory Into Practice, 41*(4), 226-232.

Mayer, R. E. (2003). Elements of science in E-learning. *Journal of Educational Computing Research, 29*(3), 297-313.

Mayer, R. E. (2005a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). New York: Cambridge University Press.

Mayer, R. E. (2005b). Introduction to multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 1-16). New York: Cambridge University Press.

Mayer, R. E. (Ed.). (2005c). *The Cambridge handbook of multimedia learning*. New York: Cambridge University Press.

Mayer, R. E., & Anderson, R. B. (1991). Animations need narrations: An experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83*(4), 484-490.

Mayer, R. E., & Anderson, R. B. (1992). The instructive animation: Helping students build connections between words and pictures in multimedia learning. *Journal of Educational Psychology, 84*(4), 444-452.

Mayer, R. E., Bove, W., Bryman, A., Mars, R., & Tapangco, L. (1996). When less is more: Meaningful learning from visual and verbal summaries of science textbook lessons. *Journal of Educational Psychology, 88*(1), 64-73.

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 93*(2), 390-397.

Mayer, R. E., Dow, G. T., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*(4), 806-812.

Mayer, R. E., Fennell, S., Farmer, L., & Campbell, J. (2004). A personalization effect in multimedia learning: Students learn better when words are in conversational style rather than formal style. *Journal of Educational Psychology, 96*(2), 389-395.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology, 82*(4), 715-726.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When static media promote active learning: Annotated illustrations versus narrated animations in multimedia instruction. *Journal of Experimental Psychology: Applied, 11*(4), 256-265.

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187-198.

Mayer, R. E., & Jackson, J. (2005). The case for coherence in scientific explanations: Quantitative details can hurt qualitative understanding. *Journal of Experimental Psychology: Applied, 11*(1), 13-18.

Mayer, R. E., Johnson, W. L., Shaw, E., & Sandhu, S. (2006). Constructing computer-based tutors that are socially sensitive: Politeness in educational software. *International Journal of Human-Computer Studies, 64*, 36-42.

Mayer, R. E., & Massa, L. J. (2003). Three facets of visual and verbal learners: Cognitive ability, cognitive style, and learning preference. *Journal of Educational Psychology, 95*(4), 833-846.

Mayer, R. E., Mathias, A., & Wetzell, K. (2002). Fostering understanding of multimedia messages through pre-training: Evidence for a two-stage theory of mental model construction. *Journal of Experimental Psychology: Applied, 8*(3), 147-154.

Mayer, R. E., Mautone, P., & Prothero, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology, 94*(1), 171-185.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*(2), 312-320.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43-52.

Mayer, R. E., Moreno, R., Boire, M., & Vagge, S. (1999). Maximizing constructivist learning from multimedia communications by minimizing cognitive load. *Journal of Educational Psychology, 91*(4), 638-643.

Mayer, R. E., & Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of Educational Psychology, 86*(3), 389-401.

Mayer, R. E., Sobko, K., & Mautone, P. D. (2003). Social cues in multimedia learning: Role of speaker's voice. *Journal of Educational Psychology, 95*(2), 419-425.

Mayer, R. E., Steinhoff, K., Bower, G., & Mars, R. (1995). A generative theory of textbook design: Using annotated illustrations to foster meaningful learning of science text. *Educational Technology Research and Development, 43*(1), 31-43.

Mayr, U., & Kliegl, R. (1993). Sequential and coordinative complexity: Age-based processing limitations in figural transformations. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(6), 1297-1320.

Mayr, U., Kliegl, R., & Krampe, R. T. (1996). Sequential and coordinative processing dynamics in figural transformations across the life span. *Cognition, 59*, 61-90.

Merrill, M. M. (2003). *The role of animated pedagogical agents in multimedia learning environment.* Unpublished Dissertation, Mississippi State University.

Miller, G., A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Moreno, R. (2005). Multimedia learning with animated pedagogical agents. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 507-523). New York: Cambridge University Press.

Moreno, R., & Flowerday, T. (2006). Students' choice of animated pedagogical agents in science learning: A test of the similarity-attraction hypothesis on gender and ethnicity. *Contemporary Educational Psychology, 31*, 186-207.

Moreno, R., & Mayer, R. E. (1999a). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*(2), 358-368.

Moreno, R., & Mayer, R. E. (1999b). Multimedia-supported metaphors for meaning making in mathematics. *Cognition & Instruction, 17*(3), 215-248.

Moreno, R., & Mayer, R. E. (2000a). A coherence effect in multimedia learning: The case for minimizing irrelevant sounds in the design of multimedia instructional messages. *Journal of Educational Psychology, 92*(1), 117-125.

Moreno, R., & Mayer, R. E. (2000b). Engaging students in active learning: The case for personalized multimedia messages. *Journal of Educational Psychology, 92*(4), 724-733.

Moreno, R., & Mayer, R. E. (2002a). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology, 94*(3), 598-610.

Moreno, R., & Mayer, R. E. (2002b). Verbal redundancy in multimedia learning: When reading helps listening. *Journal of Educational Psychology, 94*(1), 156-163.

Moreno, R., & Mayer, R. E. (2004). Personalized messages that promote science learning in virtual environments. *Journal of Educational Psychology, 96*(1), 165-173.

Moreno, R., & Mayer, R. E. (2005). Role of guidance, reflection, and interactivity in an agent-based multimedia game. *Journal of Educational Psychology, 97*(1), 117-128.

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction, 19*(2), 177-213.

Morey, C. C., & Cowan, N. (2004). When visual and verbal memories compete: Evidence of cross-domain limits in working memory. *Psychonomic Bulletin & Review, 11*(2), 296-301.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87*(2), 319-334.

Myerson, J., Hale, S., Wagstaff, D., & Poon, L. W. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review, 97*(4), 475-487.

National Telecommunications and Information Administration, & Economics and Statistics Administration. (2002). *A nation online: How Americans are expanding their use of the Internet*. Washington DC: U.S. Department of Commerce.

Niaz, M., & Logie, R. H. (1993). Working memory, mental capacity and science education: Towards an understanding of the 'working memory overload hypothesis'. *Oxford Review of Education, 19*(4), 511-525.

Norman, D. A. (1968). Toward a theory of memory and attention. *Psychological Review, 75*(6), 522-536.

Paas, F., Camp, G., & Rikers, R. (2001). Instructional compensation for age-related cognitive declines: Effects of goal specificity in maze learning. *Journal of Educational Psychology, 93*(1), 181-186.

Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational psychologist, 38*(1), 1-4.

Paas, F., Van Gerven, P. W. M., & Tabbers, H., K. (2005). The cognitive aging principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 339-354). New York: Cambridge University Press.

Paivio, A. (1971). *Imagery and verbal processes*. New York: Holt, Rinehart and Winston.

Paivio, A. (1990). *Mental representations: A dual coding approach*. New York: Oxford University Press.

Paivio, A., Clark, J. M., & Lambert, W. E. (1988). Bilingual dual-coding theory and semantic repetition effects on recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14*(1), 163-172.

Penney, C. G. (1989). Modality effects and the structure of short-term verbal memory. *Memory & Cognition, 17*, 398-422.

Peterson, L., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology, 58*(3), 193-198.

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction, 12*, 61-86.

Reed, S. K. (2006). Cognitive architectures for multimedia learning. *Educational Psychologist, 41*(2), 87-98.

Reutter-Lorenz, P. A., Stanczak, L., & Miller, A. C. (1999). Neural recruitment and cognitive aging: Two hemispheres are better than one, especially as you age. *Psychological Science, 10*(6), 494-500.

Rieber, L., P. (2005). Multimedia learning in games, simulations, and microworlds. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 549-567). New York: Cambridge University Press.

Salthouse, T. A. (1988). Resource-reduction interpretations of cognitive aging. *Developmental Review, 8*, 238-272.

Salthouse, T. A. (1994). Aging associations: Influence of speed on adult age differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*(6), 1486-1503.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403-428.

Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27*(5), 763-776.

Salthouse, T. A., Mitchell, D. R., Skovronek, E., & Babcock, R. L. (1989). Effects of adult age and working memory on reasoning and spatial abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(3), 507-516.

Scheibel, A. B. (1996). Structural and functional changes in the aging brain. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (4 ed., pp. 105-128). San Diego: Academic Press.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*(1), 1-66.

Shah, P., Mayer, R. E., & Hegarty, M. (1999). Graphs as aids to knowledge construction: Signaling techniques for guiding the process of graph comprehension. *Journal of Educational Psychology, 91*(4), 690-702.

Shiffrin, R. M., & Atkinson, R. C. (1969). Storage and retrieval processes in long-term memory. *Psychological Review, 76*(2), 179-193.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*(2), 127-190.

Solso, R., L. (2001). *Cognitive psychology* (Vol. 6). Needham Heights, MA: Allyn & Bacon.

Stark, R., Mandl, H., Gruber, H., & Renkl, A. (2002). Conditions and effects of example elaboration. *Learning and Instruction, 12*, 39-60.

Stoltzfus, E. R. (1993). Investigations of inhibition and interference in younger and older adults. *Journal of Gerontology, 48*(4), 179-188.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295-312.

Sweller, J. (1999). *Instructional design in technical areas*. Australia: ACER Press.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 19-30). New York: Cambridge University Press.

Sweller, J., & Chandler, P. (1994). Why some material is difficult to learn. *Cognition & Instruction, 12*(3), 185-233.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load as a factor in the structuring of technical material. *Journal of Experimental Psychology: General, 119*(2), 176-192.

Sweller, J., & Levine, M. (1982). Effects of goal specificity on means-ends analysis and learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8*(5), 463-474.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Tarmizi, R. A., & Sweller, J. (1988). Guidance during mathematical problem solving. *Journal of Educational Psychology, 80*(4), 424-436.

Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When two sensory modes are better than one. *Journal of Experimental Psychology: Applied, 3*(4), 257-287.

Van Gerven, P. W. M., Paas, F., & Tabbers, H., K. (2006). Cognitive aging and computer-based instructional design: Where do we go from here? *Educational Psychology Review, 18*, 141-157.

Van Gerven, P. W. M., Paas, F., Van Merrienboer, J. J. G., Hendriks, M., & Schmidt, H. G. (2003). The efficiency of multimedia learning into old age. *British Journal of Educational Psychology, 73*, 489-505.

Van Gerven, P. W. M., Paas, F., Van Merrienboer, J. J. G., & Schmidt, H. G. (2000). Cognitive load theory and the acquisition of complex cognitive skills in the elderly: Towards an integrative framework. *Educational Gerontology, 26*, 503 - 521.

Van Gerven, P. W. M., Paas, F., Van Merrienboer, J. J. G., & Schmidt, H. G. (2002). Cognitive load theory and aging: Effects of worked examples on training efficiency. *Learning and Instruction, 12*, 87-105.

Van Gerven, P. W. M., Paas, F., Van Merrienboer, J. J. G., & Schmidt, H. G. (2006). Modality and variability as factors in training the elderly. *Applied Cognitive Psychology, 20*, 311-320.

van Merrienboer, J. J. G., & Ayres, P. (2005). Research on cognitive load theory and its design implications for e-learning. *Educational Technology Research & Development, 53*(3), 5-13.

Veronikas, S., & Shaughnessy, M. F. (2005). An interview with Richard Mayer. *Educational Psychology Review, 17*(2), 179-189.

Ward, M., & Sweller, J. (1990). Structuring effective worked examples. *Cognition and Instruction, 7*(1), 1-39.

Waugh, N. C., & Norman, D., A. (1965). Primary memory. *Psychological Review, 72*(2), 89-102.

Welford, A. T. (1985). Changes of performance with age: An overview. In N. Charness (Ed.), *Aging and human performance* (pp. 333-365). New York: Wiley.

Wingfield, A., Stine, E. A., Lahar, C. J., & Aberdeen, J. S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research, 14*(2), 103-107.

Wittrock, M. C. (1990). Generative processes of comprehension. *Educational Psychologist, 24*(4), 345-376.

Zacks, R., & Hasher, L. (1997). Cognitive gerontology and attentional inhibition: A reply to Burke and McDowd. *Journals of Gerontology Series B: Psychological Sciences & Social Sciences, 52B*(6), 274-283.

Footnote

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