MULTIMEDIA LEARNING: COGNITIVE INDIVIDUAL DIFFERENCES AND DISPLAY DESIGN TECHNIQUES PREDICT TRANSFER LEARNING WITH MULTIMEDIA LEARNING MODULES

by

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A DISSERTATION

IN

EXPERIMENTAL PSYCHOLOGY

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

DOCTOR OF PHILOSOPHY

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ACKNOWLEDGEMENTS

My sincere gratitude goes to Dr. William S. Maki, committee chair, for providing four years of guidance, direction, and encouragement. In addition, I appreciate the experimental design assistance and content suggestions made by my committee: Dr. Kathryn Bleckley, Dr. Patricia DeLucia, Dr. Francis Durso, and Dr. Darcy Reich. A special note of thanks goes to my father, Dr. Larry M. Austin, for his editorial assistance and insightful comments throughout my graduate education. I also appreciate the tireless support and encouragement that I received from my precious mother, Jill C. Austin. I offer a final note of appreciation to Texas Tech University—the many faculty and administrators-- for supporting me in my professional and educational role.

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ABSTRACT

Psychologists and engineers continue to debate the efficacy of technology interfaces and merit of information display approaches. In the wake of the information explosion and rapidly progressing technology, Mayer (2001) formulated a theory that focused on human cognition, rather than technology capacity and features. Mayer and colleagues have developed a simple model, the Cognitive Theory of Multimedia Learning, suggesting that certain combinations of multimedia optimize learning, in terms of retention and transfer. The present dissertation suggests that the conclusions are premature and a much more complex set of individual differences and display design principles must be evaluated. Further, the Cognitive Theory of Multimedia Learning is vulnerable in terms of its simplistic view of information processing and working memory. For instance, when previous research tested individual difference attributes, such as spatial ability and prior knowledge, performance was evaluated only in the animation and narration condition, representing one of his three initial experimental conditions (Mayer, 2001). The present research offers a rigorous comparative analysis of the multimedia conditions. In addition, variables such as working memory, multimedia comprehension skill, and fluid intelligence are measured and isolated, so that the multimedia combination effect on transfer learning can be evaluated beyond these cognitive abilities. By measuring the effect of cognitive individual differences and display design manipulations on transfer test performance, the current research offers a broader approach to testing the impact of multimedia combinations on transfer test performance. The present research concludes that while cognitive primitives contribute to learning transfer in a multimedia lesson,

display design manipulations involving text location and the absence of motion remove the effects reported in previous research. Ultimately, there is no “magic bullet” combination of multimedia (animation and narration). Rather, key design principles coupled with the influence of cognitive individual differences must be investigated further before prescriptive guidelines for educational multimedia can be proffered. Likewise, the predictive validity of cognitive primitives, such as fluid intelligence, may redirect interest back to fundamental individual differences, as indicators of learning differences with or without the effect of technology.

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CHAPTER I

INTRODUCTION

With the development of user-friendly multimedia design tools engendered by increasing accessibility of the World Wide Web and computer technology, researchers began to examine the use of multimedia in the learning process (Maki & Maki, 2002; Maki, Maki, Patterson, & Whittaker, 2000; Niederhauser, Reynolds, Salmen, & Skolmoski, P., 2000; Shapiro, 1998; Zhang, 1996). Much of this work was conducted from the vantage point of technology design and optimizing attributes of the interface (Norman, 1986). Mayer (2002) contended that investigations have focused on manipulating and testing specific aspects of the interface or the content structures, and most of the work has lacked a unifying theoretical approach grounded in cognitive psychology. Mayer (2001) contended that the typical approach to multimedia design is a technology-centered approach based on the metaphor of learning as information acquisition. In an effort to bridge the gap between current empirical interface investigations and cognitive psychology, Mayer (2001) developed and empirically tested a theory of multimedia learning based on cognitive psychology.

While Mayer (2001) concocted the basic theoretical and empirical foundation for a multimedia approach based on cognitive theory, he noted that further research must be conducted to define the parameters, constraints, and conditions that modulate the principles of multimedia learning. The present dissertation examines two of the primary principles of multimedia learning (modality and redundancy) by means of a methodical examination of the relationship between the two foundational multimedia effects and the following cognitive individual difference variables: multimedia comprehension skill, fluid intelligence, and working memory capacity. Initial predictions suggest that cognitive individual differences would account for unique variance in test scores and moderate the effect between multimedia condition and test scores. The research further predicted that any remaining variance associated with multimedia condition assignment could be accounted for my display design manipulations. While the research found cognitive individual differences to predict unique variance in test scores, no interaction between multimedia condition assignment and cognitive individual differences was found. However, the present research demonstrated that any remaining effect of multimedia combination on transfer test scores can be eliminated with text and motion display manipulations, based on HCI principles, of the experimental materials.

Overview of the Cognitive Theory of Multimedia Learning (CTML)

The CTML rests on three basic assumptions underlying this approach: dual channel processing, limited capacity, and active processing (Mayer, 2001; Mayer, 2002). First, the dual channel processing assumption is based on the seminal work by Paivio (1986), which posited that humans have distinct channels for processing visual and auditory information. Paivio (1986) inspired current conceptions of working memory, suggesting two separate channels for processing visual and auditory stimuli. In previous research, Baddeley and Hitch (1974) described the components of working memory as the phonological loop, the visuo-spatial sketchpad, and the central executive. The central executive is a modality-free, attentional-control system that manages the phonological loop and the visuo-spatial sketchpad. [1] The phonological loop encodes verbal information and the visuo-spatial system encodes pictorial and spatial information.

Second, the human working memory system has limited capacity and is susceptible to overload (Baddeley, 1999). Mayer (2001) suggested that the limited capacity nature of memory causes the learner to be susceptible to extraneous cognitive load, which depends on the organization and presentation of the learning material. In general, cognitive load is the total resource requirement placed on working memory for a given task. Extraneous cognitive load represents activity that consumes cognitive resources and is not relevant to the task at hand (Sweller, 1994). Hegarty, Narayanan, Freitas, (2002) and Sweller (1988) documented that extraneous cognitive load decreased resources available for learning, resulting in diminished performance on problem-solving tests.[2] Mayer (2001) demonstrated that extraneous cognitive load forced students to process learning material inefficiently, which led to poorer performance on retention and transfer tests.

Third, in order for learning to be transferred and retained, the learner must actively process by attending to incoming information, organizing the information into a coherent mental representation, and integrating the current mental representation with prior information (Anderson, 2000; Baker & Mayer, 1999; Moreno, Mayer, Spires, & Lester, 2001). The CTML contends that active learning is more than kinesthetic activity and requires cognitive engagement (Mayer 2001).

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[1] Baddley and Hitch (1974) refer to the phonological loop and the visuo-sptaial sketchpad as “slave” systems, as they are monitored by the central executive.
[2] Note that an individual can also be cognitively overloaded by task-relevant aspects of the multimedia learning module, which is referred to as intrinsic cognitive load.

Based on these three assumptions, the CTML outlined seven principles of multimedia design and evaluated each principle in terms of student retention and transfer (Mayer, 2001; See Appendix A for further detail):

- multimedia principle (people learn better from words and pictures than from words alone);
- spatial contiguity principle (people learn better when related words and pictures are in close proximity);
- temporal contiguity principle (people learn better when related words and pictures are close together in time);
- coherence principle (people learn better when irrelevant words, pictures, and sounds are eliminated from the presentation);
- modality principle (people learn better from narration and animation than from text and animation);
- redundancy principle (people learn better from narration and animation compared to animation, narration, and text); and
- individual differences principle (individuals with low prior content knowledge and individuals with high spatial skills benefit most from animation and narration-presented materials).

Of the aforementioned principles, the CTML explained modality and redundancy effects in terms of cognitive architecture and working memory design. Hence, the modality and redundancy principles are grounded in cognitive theory and are paramount to the theory of multimedia learning and the foundation for the associated principles

(Mayer, 2002). The current research focuses on the modality and redundancy principles, and suggests several additional individual differences and design principles that may further define the relationship between transfer test performance and the modality and redundancy principles.

Assessment of Multimedia Learning

In terms of learning assessment, previous research focused on transfer learning (Mayer, 2001; Mayer, 2002). Noting that retention is an important aspect of learning, the CTML contended that deeper learning occurs when students can transfer the concepts and process to a novel situation, and can demonstrate understanding by inference and induction. The theory of multimedia learning focused on a demonstration of various design principles, with transfer and retention performance measured by short assessments following a scientific, process-oriented learning module. The transfer test included troubleshooting, redesign, prediction, and conceptualization questions. Note that the assessment instruments used in previous research have not been subjected to item-level reliability analysis. The transfer tests administered were composed of conceptual, re-design, troubleshooting, and prediction questions (Mayer, 2001).

Modality Principle

The modality principle suggests that a combination of animation (pictorial) and narration (auditory) materials yielded better retention and transfer performance compared to a combination of written (textual) and animation (pictorial) (Mayer, 1998; Mayer, Heiser, & Lonn, 2001; Mayer & Moreno, 1998; Mayer & Moreno, 2002; Moreno & Mayer, 1999). Moreno and Mayer (1999) defined the modality effect as the superiority of animation and narration (spoken words and pictures) compared to animation and text (spoken words and written words) in multimedia learning modules. The effect was measured in terms of student performance on retention and transfer tests. Previous research argued that the modality effect illustrates the fundamental concept of limited capacity, suggesting that the animation and narration combination is optimal for interaction between the visuo-spatial sketch pad and the phonological loop (Mayer, 2001). The animation and narration combination allows the learner to use each channel simultaneously, instead of burdening one stimulus pathway. For example, Moreno and Mayer (2004) randomly assigned participants to one of two multimedia conditions (animation and text or animation and narration) of a "lightning lesson". The lightning lesson is a short, scientific multimedia lesson that explains how lightning works. Figure 1 exhibits two excerpts from the lightning lesson. Note that in all conditions, text appears at the bottom of the screen and scrolls in a word-by-word procession across the screen. The Animation, Narration, and Text (ANT) condition appears exactly the same, but includes redundant audio; written text and audio text are equivalent.

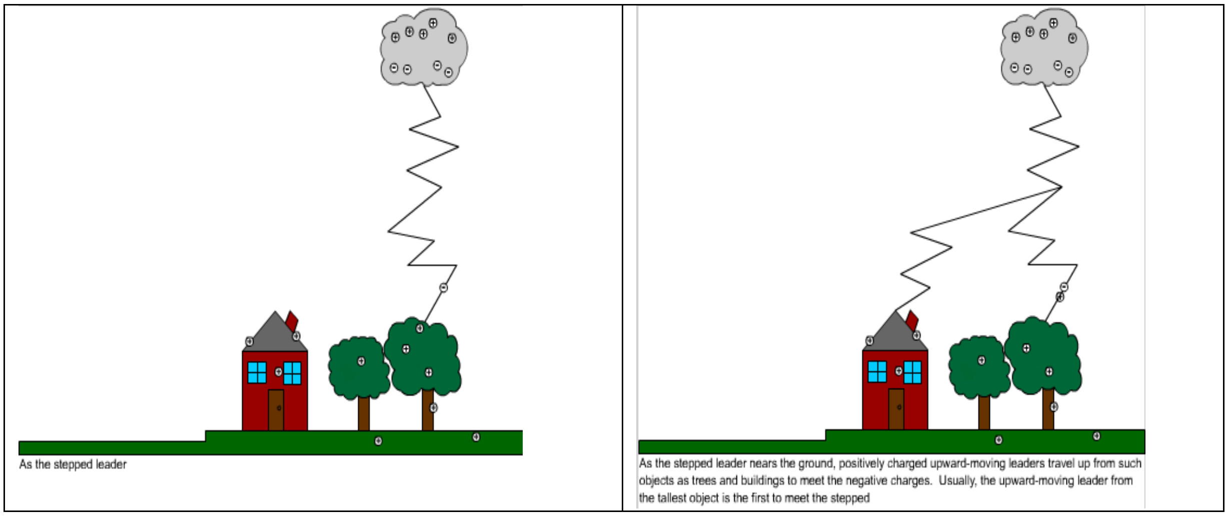

Figure 1. Original Mayer Animation and Text (AT) condition

Each participant completed a retention test immediately following the multimedia lesson. The CTML contended that the animation and text condition overloaded the visio-spatial sketchpad, as the lesson forced students to read text and view pictures. Moreno and Mayer reported a moderately strong effect for animation and narration (d=.80)[3]. In another experiment series, Mayer and Moreno (1998) randomly assigned participants to the same two multimedia conditions of the lightning lesson and administered a transfer test immediately following the multimedia lesson. They reported a strong effect for animation and narration in the transfer condition (d=1.68)[4]. Again, the authors concluded that animation and text required a suboptimal allocation of cognitive resources; learners had to contend with an overtaxed visual pathway and an idle auditory pathway.

Other researchers have pursued similar experimental approaches. Kalyuga, Chandler, and Sweller (1999) also concluded that the working memory system becomes

[3] Cohen's d measures the magnitude of the effect size. .80 is a large effect, equivalent to an R-squared of 47.4% (variance in test scores accounted for by multimedia condition).
[4] Cohen's d of 1.68 represents 73.1% of the variance in test scores accounted for by multimedia condition.

overloaded when the visual system must process printed text and images (split attention effect). They found better comprehension (includes both a retention and a transfer component) when images were presented with auditory explanations. Lewandowski and Kobus (1993) discovered that when words were simultaneously presented visually and auditorily, performance on recall tests improved compared to either unimodal condition. Leahy, Chandler, and Sweller (2003) reported that combined visual and audio presentations were superior to equivalent visual-only presentations.

Redundancy Principle

The redundancy principle posits that animation and narration yield superior retention and transfer performance compared to animation, narration, and text as the redundant condition yielded stimulus overload on the visual pathway as subjects had to simultaneously process animation and text (Halpern & Lantz, 1974; Kalyuga, et al., 1999; Mayer, 2001; Mayer & Anderson, 1991; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer et al. 2001). In Experiment 1, Mayer, Heiser, and Lonn (2001) randomly assigned participants to the animation and narration condition or the animation, text, and narration condition. The lightning modules were used as the experimental materials, adding narrated audio to the identical textual information and animation, as described in Figure 1 above. Immediately following the multimedia lesson on lightning, participants completed a retention test. The authors reported a moderate effect size(d=.66[5]) associated with the animation and narration condition, and indicated that learners in the animation and narration condition scored higher on the retention test compared to the

[5] Cohen's d=.66 is approximately equal to 40% of the variance in test scores explained by multimedia condition.

animation, narration, and text condition participants. In Experiment 2, Mayer et al. (2001) assigned participants to the same two multimedia conditions and administered a transfer test immediately following the lesson. The authors found a strong effect size (d=1.65[6]) associated with the animation and narration condition. Hence, Mayer and colleagues suggested that the animation, text, and narration condition produced inferior learning, as measured by both retention and transfer test. They surmised that the effect was due to the visual pathway becoming overloaded with both the animation (pictures) and written text, thereby reducing the participant's learning.

Moreno and Mayer (2002) found that temporal (successive versus simultaneous) presentation mediated the redundancy effect, finding an interaction between picture and text coordination and redundancy. They also determined that the redundancy principle holds only when materials are presented simultaneously; successive presentation of all three modalities did not overload the system and reduce performance. Mayer and Chandler (2001) reported that materials without redundancy fostered deeper understanding of the scientific material, as measured by a content transfer test based on the same learning rubric as previous research. Further, Montali and Lewandowski (1996) reported that bi-modal simultaneous presentation (on-screen text and narration) yielded better performance for low-skilled readers. These findings indicate that the redundancy principle may be mediated or moderated by other design principles and by individual difference factors.[7]

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[6] Cohen's d=1.65 is approximately equal to 70% of the variance in test scores explained by the multimedia condition.
[7] Mayer (2001) acknowledged that "much additional research is needed to fully understand the role of individual differences in multimedia learning" (pp. 182).

Challenges to the CTML

Even though the CTML and the component principles of modality and redundancy have been evaluated with a specific type of information structure, perhaps the conflicting empirical reports from other researchers are merely symptoms of a larger problem. Critical analysis suggests three challenges to the fundamental precepts of the CTML (Mayer, 2001) that potentially impact the modality and redundancy principles: simple dual-channel analogy is not sufficient; working memory is more complex than the theory indicates; and the experimental approach has not been exhaustive enough to reach prescriptive instructions for educators. In terms of stimulus processing channels, the CTML, grounded in the work of Paivio (1986), suggested a simple dual-channel approach for processing visual and auditory information. However, Anderson (1983) proposed a multi-channel theory of memory, including separate codes for spatial information, abstract propositions, and temporarily organized representations. As such, evidence suggests that the simple dual-channel approach is an overly simplistic description of stimulus processing.

The dual channel supposition contained a second implicit assumption that the channels are similar in terms of processing speed and encoding. In fact, the CTML discussed the channels as if they are equal with respect to sensory processing (Mayer, 2002). In essence, dual channels of stimuli processing and transportation does not necessarily indicate that the components traveling on those pathways are equivalent or processed at the same speed. Buchtel and Butter (1988) found evidence that the auditory system is more efficient and rapid at processing environmental cues, indicating that between-modality differences might be physiological. Conflicting evidence also exists concerning cross-modal asymmetry in processing visual and auditory cues (McDonald, Teder-Saelajaervi, Heraldez, & Hillyard, 2001; McDonald & Ward, 2000; Ward, 1994). Hence, at a physiological level, some differences have been observed that might render the implicit equality assumption inaccurate. In defense of the position elucidated by the CTML, some empirical work suggested that these physiological differences have not translated into meaningful differences at the cognitive level. Gernsbacher and Varner (1988) designed narrative learning modules in each modality (textual, auditory, and pictorial) to test learner performance with respect to modality. Gernsbacher, Varner, and Faust (1990) found that comprehension skill, described as the suppression of irrelevant information, transcended the effects of modality. Hence, their findings suggested that the dual-capacity assumption and implicit sensory-processing equality assumption may be legitimate at the cognitive level, but that the relative importance of modality is less than that of individual differences in comprehension skill.

A second challenge concerns the simplistic approach to working memory adopted in previous research. Baddeley and Logie (1999) argued that "Working memory. . . comprises those functional components of cognition that allow humans to comprehend and mentally represent their immediate environment, to retain information about their immediate past experience, to support the acquisition of new knowledge, to solve problems, and to formulate, relate, and act on current goals" (pp. 28-29). Hence, working memory was not a structurally separate place in the mind that can be simplistically isolated and modeled (Miyake & Shah, 1999). Furthermore, Mayer (2001), citing

Baddeley, contended that working memory has two parallel processing paths: visual and auditory. Schnotz, Bannert, and Seufert (2002) argued, “the parallelism of text processing and picture processing assumed in this model [Mayer’s theory of multimedia learning] is problematic, however, because texts and pictures are based on different sign systems and use quite different principles of representation” (pp. 393). This suggests that working memory capacity is contingent on the type of stimulus and resulting mental representations generated, not merely the presence of distinct areas of processing. Schnotz et al. (2002) proposed a much more complex model of working memory that includes propositional representations used to construct mental models that have both serial and parallel features of modality processing, which impact the concept of capacity. Just as each channel may not be created equal, perhaps each mental representation is not created equal in terms of modality input, and the resulting coherent mental representation is a complex interaction of serial and parallel processing. In terms of the CTML, all mental representations created as a result of a particular modality stimulus cannot be presumed equal.

In terms of a strategic view of working memory, Miyake and Shah (1999) argued that the notion of working memory is not a unitary construct and must take into account a multitude of domain-specific effects, such as task requirements and response modality. Given that previous research focused on scientific texts, the modality and redundancy principles cannot be generalized to other domains without empirical research. While both expository and narrative texts use the same general cognitive structures, Van den Broek, Virtue, Everson, Tzeng, and Sung (2002) contended that “narrative texts possess a causal-temporal structure that is often more familiar to readers than the logical structure of expository texts" (pp. 149). Van den Broek et al. (2002) also noted that expository texts, while widespread in our society, are still a smaller subset of the reading material encountered by most people. Hegarty et al. (2002), after empirically evaluating static text versus animated narration for a machine manual, found no evidence that media or modality had "any effect on comprehension and learning" (pp. 380). Ultimately, any cognitive theory of multimedia learning must include a more complex notion of working memory.

As a third challenge, four deficiencies in the experimental method and design of previous research warrant further research. First, previous research has been consistently absent the pairwise comparison of all three multimedia conditions in the same experiment. Absent also is a discussion and experimental comparison of the animation and written text (used in experiments measuring the modality effect) and animation, written text, and narration (used in experiments measuring the redundancy effect). In order to comprehensively evaluate the relationships among modality combinations, one must empirically measure and compare performance in all three conditions. For instance, if animation and text are less effective on transfer tests compared to animation, text, and narration, then one must consider that the redundant text and narration might provide useful reinforcement for certain learners, as Lewandowski and Kobus (1993) reported. If animation and text conditions produce higher transfer scores compared to the animation, text, and narration condition, then the impact of redundant text and narration would appear to split attention and must be evaluated further. Even though the CTML contended that overloading the visual pathway leads to poorer performance on retention and transfer tests, previous research failed to measure the difference between the animation, narration and text condition and the animation and text condition. Regardless, if the bi-modal overload (both visual and auditory) is more or less severe than a unimodal overload (visual, with pictures and text), then one must delve further into the cognitive components than has been attempted in previous research. In essence, any statistically significant differences between any two modalities should be explored.

As a second experimental approach deficiency, the experimental design in previous research lacked consideration for a body of work that examines the relationship among our sensory modalities. Since the 1700's, psychologists assumed that our sensory modalities were separate and distinct. For instance, George Berkeley in 1709 suggested, "If we take a close and accurate view of things, it must be acknowledged that we never see and feel one and the same object. That is which is seen is one thing, and that which is felt is another. . . the objects of sight and touch are two distinct things" (Lederman & Abbott 1981 citing Berkeley, p.34). Similarly, Katz (Lederman & Abbott citing Katz, 1981) argued that touch and color are distinct entities offering independent input into our perception of the world. These early scholars fostered the modality-independent view of sensory modalities that has dominated scientific thought and investigation (Driver & Spence, 1999). However, based on research conducted in the last two decades, a second approach emerged. Proponents claimed that the functioning of modalities is largely independent, but that the modalities are linked by a physiological and cognitive mechanism (Driver & Spence, 1999; Macaluso & Driver, 2001; Rorden & Driver, 1999;

Schmitt, Postma & De Haan, 2000; Shimojo & Shams, 2001; Spence & Driver, 1997). A related position suggested that the sensory modalities are governed and regulated by a common physiological mechanism (McDonald & Ward, 2000; Martino & Marks, 2000). This integrative approach, referred to as the supra model, claims that responses in one modality influence responses in other modalities as a result of this common regulatory device in the brain (Martino & Marks, 2000). In terms of the relationship between modalities, the linked and supra models challenge the reasoning and evaluation of the independent model proffered by Berkeley and Katz.

In a seminal study, Driver found that dynamic audiovisual integration influences auditory selection pre-attentively (Driver & Grossenbacters, 1996 as cited in Driver and Spence, 1999). In this experiment, participants heard two concurrent auditory messages involving three two-syllable words in random order, and the task was to report one of the messages and ignore the other message. Distracter and target strings were not cued or identified with auditory information. The relevant message was indicated visually. The participants watched a speaker on a monitor and had to determine which message the speaker was delivering of the two being heard. The sound emanated from a point nearby the monitor or a point farther away from the monitor. The results indicated that subjects display 17% better selective shadowing when visual sources were away from the speaker. Driver concluded that ". . .(this benefit) . . .implies that selective shadowing can be objectively improved by an illusory spatial separation between target and distracter sound. . .The implication. . .is therefore that some cross-modal integration can take place between audition and vision before auditory spatial selection is fully completed" (Driver

& Spence, 1999, p. 146). Even a brief look at the voluminous body of work on cross-modal attention and sensory modality interaction, motivates the need to examine all three multimedia modality combinations in the same experimental condition. In essence, the CTML assumes stimuli presented in all sensory modalities are processed equally, while the aforementioned evidence suggests that some cross-modal sensory stimuli are processed more efficiently and others less efficiently.

A third area warranting additional research is the role of cognitive individual differences. Other than one set of experiments (Mayer & Sims, 1994), previous research has not considered the role of cognitive individual differences. Even though many subtle individual differences are accounted for in the process of random assignment in a normally distributed population, cognitive individual differences are a critical factor in any learning manipulation. Given that the modality and redundancy effects emanate from cognitive theory, measuring the relationship between cognitive individual differences and modality condition assignment is necessary to isolate the effect of multimedia condition. Without experimentally controlling for cognitive individual differences, the size of any multimedia condition effect may be distorted. Sternberg (1996) discussed the critical role of ability measurement in developing treatments to improve learning. Ackerman, Beier, and Bowen (2002) highlighted the importance of individual cognitive abilities in any consideration of instructional manipulation and student performance. Alwin (1994) suggested that considerations of ability differences are important across the life span, contending that learning is a life-long endeavor.

Although learning certainly entails more than aptitude, aptitude must also be measured when introducing a pedagogic treatment designed to improve retention or transfer.

A fourth deficiency in the design of experimental method and materials is that the interaction of attention and display design has only been partially considered in the CTML. As cited earlier, previous research discussed the impact of split attention in terms of modality stimulus input, but did not fully consider the impact of display design on attentional capture. Models of attention have largely focused on two distinct aspects of attention: perceptual processes and cognitive elements (Schiffrin & Grantham, 1974). Perceptual or systematic attention is usually held to comprise those interactions and reactions that occur prior to attention. Cognitive elements involve higher order assimilations, decisions and, notwithstanding automaticity, involve attention. Two distinct forms of attention have long been acknowledged: exogenous and endogenous. Exogenous attention is reported to be quick and almost automatic (Yantis & Jonides, 1990). Endogenous attention is thought to be "consciously controlled and relatively slow" (Schmitt et al. 2000). Exogenous information can cause an overt shift in attention in one sensory modality accompanied by a concomitant shift in another sensory modality (Driver & Spence, 1999). In fact, Driver and Spence repeatedly demonstrated this phenomenon with vision, audition, and touch in an elevation discrimination task, concluding that exogenous cues lower response time compared to endogenous cues (Driver & Spence, 1999; Spence & Driver, 1994; Spence & Driver, 1996). Upon reviewing Mayer's display design for the lightning lesson, the present research (Experiments 3 and 4) examines components of the display design that serve as exogenous distracters, interrupting attentional focus and distracting from the learning process. Mayer has certainly contributed to our understanding of multimedia presentation and learning, but further theoretical and scientific exploration is required before guidelines can be designed for educators.

CHAPTER II

IMPORTANCE OF DISPLAY DESIGN PRINCIPLES

In assessing the importance of display design in terms of transfer learning from a multimedia lesson, perception of the display is of paramount importance. The direct theory of perception suggests that the display design had a significant role in any computerized multimedia learning investigation. In a revolutionary and distinct approach to perception, Gibson (1979) argued that perception is not based on neural stimulation contingent on a retinal image, but on information pick-up from the optic array. He argued that all of the information necessary for perception can be found in the sea of physical energy that includes substances, media, and surfaces (Gibson, pp. 1-4). The ambient light reaching our eyes is rich in pattern and change; Gibson suggested that we register the invariants of the changing structure to determine our perception (pp. 52-64). This holistic approach to perception suggested that the perceptual system is composed of various organs that all contribute to perception (pp. 238-255). One relevant conclusion that Gibson posited is that we see what an object "affords" and the important measurement to consider is the dimensions of variation of form. (p. 197). While the concept of affordance evolved over time, scientists have continued to wrestle with the fundamental concept and scientific applications (Greeno, 1994; Jones, 2003). Gibson's (1979) final definition of affordance was, "a specific combination of the properties of its substance and its surfaces taken with reference to an animal" (p. 67).

The affordance concept has been applied to display design in terms of identifying the properties of the display screen and their impact on perception and processing (Strong

& Strong, 1991). Hartson (2003) suggested four complementary types of interface display affordances: cognitive affordance, physical affordance, sensory affordance, and functional affordance. Applied to computerized multimedia learning lessons, clearly the physical affordance (such as display size, resolution, and shape) and the sensory affordance (components of the multimedia lesson display, such as audio, pictorial, and textual information) are relevant considerations in display design. St. Amant (1999) explained affordances with respect to interface design in terms of four basic properties: display component interactions, possible actions in the interface, perceived display properties, and internalized mental constructs. Applying the general conception of object affordances to multimedia learning, computer display and multimedia components have affordances that impact perception and processing.

A second compelling argument highlighting the importance of display design originated from the computer science vantage point, and suggested that the interface is an independent means of communication in the internal input-output system (Norman, 1998; Sutcliffe, Ryan, Doubleday, & Springett, 2000). Engineers argued that a user-centered design is the optimum approach to display design. Specifically, the direct manipulation approach to interface design suggested that two aspects of "directness" are critical: distance and engagement (Hutchins, Hollan, and Norman, 1986). "Direct" in this context refers to the relationship between the user and functionality in the interface. This approach suggested that regardless of multimedia content, the physical design of the display was important to consider.

A third case for display design importance is based on the distributed information resources approach to human-computer interactions. Specifically, information structures present in the display supported information-processing tasks (Wright, Fields, and Harrison, 2000). The theory postulated three forms of interface communication: information retrieval, comparison, and interaction. While this theory is more deeply entrenched in traditional cognitive theory stemming from connectionist networks and mapping, the resources model acknowledged that task success is partially display dependent. Various studies have examined each type of interface communication and the role of display design (Golightly & Gilmore, 1997; Howes & Payne, 1990; Wright et al., 2000). Wright et al. (2000) conclude that, "our studies, by using versions that differed only in the resource representations, provide stronger evidence that the design of external resources is an important factor in determining interaction strategy" (2000, p. 35).

A final case for display significance emanates directly from traditional cognitive theory. Cognitive theory identified two types of cognitive load: intrinsic and extraneous. Relevant here is a brief discussion of extraneous cognitive load. Extraneous cognitive load is the "demand placed on working memory due to the manner in which the material is presented, and/or the activities required of the learner" (Niederhauser et al. 2000, p. 250). As such, a poorly designed interface increased the demands on working memory, increased the summative cognitive load, and reduced learning. While this model required cognition for perception to occur, the approach supported the hypothesis that the display is an integral part of perception and information processing. These four eclectic areas of study offer the foundation for a theoretical justification for scientifically examining the role of display design in multimedia learning.

Four experiments were designed to address the aforementioned theoretical and experimental issues. Experiment 1 replicated the experimental conditions that Mayer and colleagues used and reviewed all pairwise comparisons, in an attempt to replicate Mayer and to evaluate the relationship between the animation and text condition and the animation, narration, and text condition. Experiment 2 was designed to measure the impact of cognitive individual differences (working memory, multimedia comprehension skill, and fluid intelligence) on transfer test performance. Additionally, Experiment 2 evaluated the possible interaction between cognitive ability and multimedia condition, in terms of transfer test performance. Experiments 3 and 4 evaluated the impact of display design by manipulating text positioning (Experiment 3) and motion (Experiment 4).

Results suggest that multimedia condition assignment accounted for variance in transfer test scores above and beyond the impact of cognitive individual differences of fluid intelligence, working memory, and comprehension skill. Experiment three and four demonstrated that aspects of the display design accounted for the inferiority of transfer test performance in the AT and ANT conditions. In Experiment 3, repositioning text removed the superiority of transfer test performance in the animation and text condition compared to transfer test performance in the animation and narration condition. Experiment 4 demonstrated that removing text scrolling eliminated the superiority of transfer test performance in the animation, narration, and text condition compared to transfer test performance in the animation and narration condition. The current research concludes that superior performance in the animation and narration condition was an artifact of display design attributes of the experimental materials.

CHAPTER III

EXPERIMENT 1 – MAYER REPLICATION AND ALL PAIRWISE COMPARISONS

Experiment 1 examined the relationship between multimedia condition and transfer test score in an attempt to replicate the modality and redundancy effects (Mayer, 2001). Mayer and Moreno (1998) found that participants assigned to the animation and narration condition performed better on the content transfer test compared to participants in the animation and text condition or the animation, text, and narration condition. Mayer (2001) found that animation and narration yielded superior transfer scores compared to the animation and text condition as the modality effect, and reported that animation and narration yielded superior transfer scores compared to the animation, narration, and text condition as the redundancy effect. Experiment 1 replicated these two elemental components of the CTML and evaluated the relationship between the animation and text condition and the animation, text, and narration condition.

Method

Participants. Seventy-five participants (thirty-nine females, thirty-six males) were randomly assigned to a multimedia condition in exchange for course credit in a general psychology course at Texas Tech University. Experiments were conducted in a university Windows-based computing lab with 18 available workstations. All participants reported normal hearing ability.

Materials. For the multimedia lesson, Mayer's (2001) lightning modules from an old version of Director (for the Macintosh) were converted to Macromedia Flash modules (for the PC). The three basic conditions were generated using Mayer's exact script, timing, and simple images: animation and text (AT), animation, narration, and text (ANT), and animation and narration (AN). The animations contained the same series of sixteen animations, as illustrated in Figure 1.

Procedure. After all participants were seated, they were instructed that they would experience a short multimedia lesson, followed by a brief test. Regardless of multimedia assignment, all participants wore headsets and were told that their presentation may or may not include audio, text, and pictorial information. After instructions, all participants tested their audio headsets to ensure proper functioning. Headsets were durable and included padded ear cuffs to eliminate environmental noise from other presentations. All participants began the lesson at the same time. Once all the multimedia lessons had finished playing, participants were asked to remove their headsets, exit the program, and logoff of the computer. A transfer test was administered with paper and pen; participants were allotted ten minutes to complete the transfer test, as Mayer (2001) specified. The content transfer test used in Experiment 1 was the exact test that Mayer and colleagues administered. The test was comprised of four questions: a redesign question, a troubleshooting question, a prediction question, and a conceptual question (Table 1).

Table 1. Multimedia transfer test items and answer key (Mayer 2001, pp. 29-30)

Type	Question	Acceptable Answers
Redesign	What could you do to decrease the intensity of lightning?	1. Remove positive particles from the earth's surface 2. Placing positive particles near the cloud
Troubleshooting	Suppose you see clouds in the sky but no lightning. Why not?	1. Top cloud may not be above freezing level 2. No ice crystals form
Prediction	What does air temperature have to do with lightning?	1. Earth's surface is warm and oncoming air cool 2. The top of the cloud is above freezing level and the bottom cloud is below freezing level
Conceptual	What causes lightning?	1. Differences in electrical charge within the cloud 2. Differences in air temperature within the cloud

Note: common sense answers not counted as correct; scored for meaning not verbatim from key

Tests were collected and participants briefed on the nature of the study. All aspects of the procedure and method were administered exactly as specified in previous research cited above.

Scoring. Each transfer test was scored by two raters; the experimenter and a second academician that was not involved in the data collection. Raters used the scoring criteria outlined by Mayer (2001) and further delineated by Moreno and Mayer (2002). At the time of scoring, neither rater had knowledge of individual condition assignment. As reported by Moreno and Mayer (2002), each transfer question had a list of acceptable answers, each worth one point. No points were awarded for common sense answers. Table 1 above lists the acceptable answers. A comparison between the two scorers using Pearson's correlation coefficient yielded $r = .96$, indicating a strong, positive, reliable consistency between evaluators.

Results

Experiment 1 replicated the aforementioned research: animation and narration multimedia materials yield higher scores compared to animation and text or animation, text, and narration. Additionally, AT and ANT conditions were not significantly different in terms of transfer test performance. Table 2 displays the means and standard deviations for the three multimedia conditions.

Table 2. Experiment 1 descriptive statistics for multimedia conditions
(Transfer test score scale 1 – 9)

Condition	N	Mean	Standard Deviation
Animation & Text (AT)	25	1.68	.69
Animation, Narration, & Text (ANT)	25	1.92	.81
Animation & Narration (AN)	25	2.92	1.41

Figure 2 illustrates the relationship among the means.

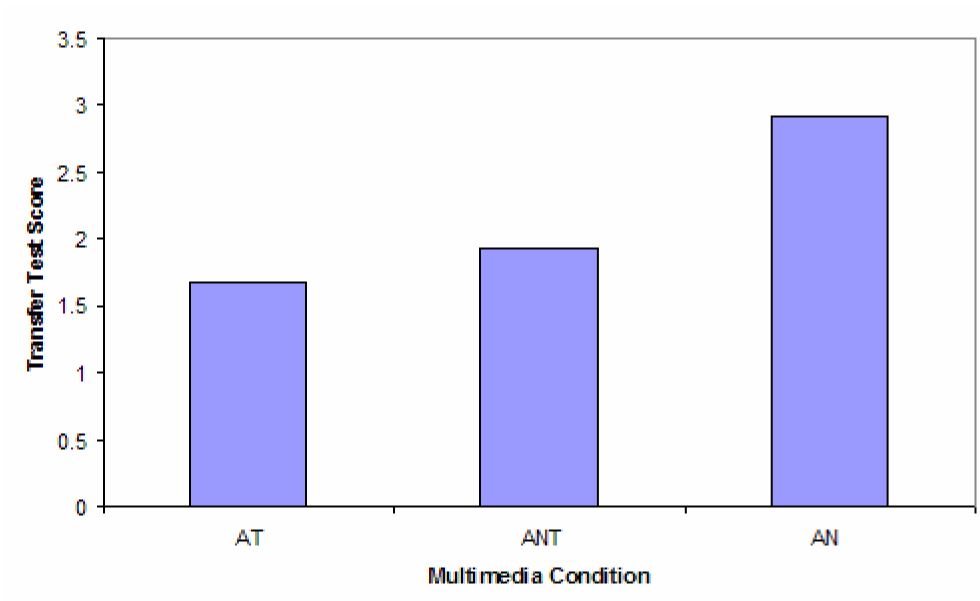

Figure 2. Multimedia condition, group mean differences (Total possible score on transfer test = 9)

An analysis of variance indicates group differences beyond chance probability occurrence *F*(2,74)=4.01, *MSE*=1.04, *p*<.001. Two-tailed t-test analyses between the animation and text (AT) group and the animation and narration (AN) group (modality principle) revealed that AN scores were higher than AT scores t(48)=3.95, p<.001.[8] In terms of Mayer's (2001) redundancy principle, two-tailed t-test analyses between the animation, narration, and text (ANT) and the AN group revealed that AN scores were higher than ANT scores t(48)=3.07, p=.001.[9] As previously discussed at length, Mayer did not discuss the relationship between ANT and AT, but the current research found that ANT scores were not significantly different from AT scores, t(48)=1.13, p=.94. With the modality and redundancy effects replicated, the role of cognitive individual differences was examined in Experiment 2.

[8] Levene's test for equal variances indicated that the homogeneity assumption is valid for the two group comparison, F=9.187, *MSE*=.314, p=.004.
[9] Again, the assumption of homogeneity was confirmed with Levene's test for equality of variance, F=7.593, *MSE*=326, p=.008.

CHAPTER IV

EXPERIMENT 2 – COGNITIVE INDIVIDUAL DIFFERENCES

Given the replication in Experiment 1, the impact of cognitive individual differences on multimedia condition and transfer test score was examined. Experiment 2 was designed to measure the impact of working memory, measured by operating span (OSPAN); multimedia comprehension skill, measured by the Multimedia Comprehension Battery (MMCB); and fluid intelligence, measured by Raven's Progressive Matrices (RMI - short form) on the relationship between multimedia condition and transfer test score.

Working memory is of particular interest for two fundamental reasons: the importance of working memory in language comprehension; and the relationship between working memory and fluid intelligence. The role of working memory in language comprehension has been extensively evaluated (see Gathercole & Baddeley, 1993 for an extensive discussion). Gathercole and Baddeley (1993) and Baddeley (1996) concluded that the central executive plays a critical role in language and quantitative comprehension. In a manipulation of reading comprehension, evidence indicated that working memory could play a key role in performance (Turner & Engle, 1989). For instance, those with high working memory capacity may be able to master the lesson material regardless of multimedia combination. Likewise, students with low working memory capacity may not have the resources to process multimodal or redundant information as efficiently, compared to high-span students. In either case, working memory capacity must be tested for an interaction with multimedia condition. Given the earlier challenges to Mayer's simple approach to working memory, individual span differences could conceivably mediate the modality and redundancy principles that Mayer (2001) elucidated. Miyake and Shah (1999) highlighted the importance of working memory span for parallel processing. Given a more intricate view of working memory involving serial and parallel processing, working memory span is an important individual difference to investigate.

In terms of the relationship between working memory and fluid intelligence, Kyllonen (1996) initially argued that working memory was equivalent to general intelligence, while most others contended that the association between working memory and fluid intelligence was strong and positive (Engle, Tuholski, Laughlin, & Conway, 1999; Lohman, 1999). Engle et al. (1999) argued that working memory and fluid intelligence represent the ability to keep a representation active. Anderson (1983) contended that the ability to keep a representation active impacts learning ability. In order to thoroughly examine the role of multimedia condition on transfer learning, the variance in test scores associated with this fundamental ability should be measured and accounted for before attributing the variance to multimedia condition assignment. An interaction between an ability to keep a representation active and multimedia condition would suggest that the modality and redundancy conditions, and associated effects on transfer learning, are moderated by a temporally prior ability. Intuitively, such ability would impact multimedia learning and comprehension.

Multimedia comprehension skill is another cognitive individual difference that should be factored into the explanation of transfer test performance. Gernsbacher and

Varner (1988), in a within subjects experimental design, presented multimedia materials unimodally (visual, auditory, and textual) and concluded that a single construct, comprehension skill, transcends any modality effect. In contrast, Mayer and his colleagues deployed a multimodal scheme (animation & narration, animation & text, animation, narration, and text) and concluded that the animation and narration combination yields superior performance on transfer tests. One fundamental difference between the two approaches is the type of text used in experimental manipulations. Gernsbacher used narrative, fictional text adapted from children's stories. Mayer used brief scientific texts aimed at practical and analytical processes. Given that both require the development of a mental representation or model for comprehension and transfer, the text difference does not impede the common, fundamental, and shared goal of each experiment: the examination of comprehension based on stimuli inputs (Van den Broek, 1994; Van den Broek, Virtue, Everson, Tzeng, & Sung, 2002).

The present research contends that the unimodal and multimodal depiction of multimedia comprehension must be evaluated simultaneously in order to shed light on the discrepancy. If the unimodal comprehension skill approach is paramount, then comprehension skill will predict more score variance than multimedia condition. If the multimodal comprehension approach is more accurate, then multimedia condition, specifically animation and narration, will predict more variance than multimedia comprehension skill. A third result might be the dual importance of both approaches, statistically expressed in main effects or interaction effects. Mayer and Sims (1994) set a precedent for such interactions when they examined subject spatial ability, reporting that subjects with low spatial ability benefited more from the animation and narration condition compared to high spatial ability subjects.

Fluid intelligence is the third cognitive ability that warrants consideration in the evaluation of multimedia condition on transfer learning. The results of Carroll's (1993) meta analysis, suggested a concrete definition of fluid intelligence. Carroll (1993) described fluid intelligence as "basic intellectual processes of manipulating abstractions, rules, generalizations, and logical relationships" (p. 583). Carroll (1996) suggested that general fluid intelligence is likely to be a factor when the individual has "minimal environmental exposure" to the particular content being tested (p.16). Fluid intelligence has also been associated with spatial ability (Lohman, 1996) and working memory capacity (Kyllonen, 1996). Factor analytic meta-analysis supported the notion of a broad fluid ability that is a priori to narrower cognitive skills such as induction, visualization, and sequential reasoning (Carroll, 1993, p. 634). The ubiquitous, a priori construct of general fluid intelligence, as evidenced by Carroll's (1993) placement of fluid intelligence in the second stratum, which is not contingent on specific domain knowledge and a critical component of intelligence and learning, appears to be a relevant factor to consider in evaluating the modality and redundancy effects related to multimedia learning. Even if one is not compelled by factor analytic techniques, the fact remains that the influence of fluid intelligence should at least be covaried out of the analysis before examining the effect of multimedia condition on transfer test score.

In terms of cognitive individual differences, domain specificity expertise (Sims & Mayer, 2002; Mayer & Gallini, 1990) and spatial ability (Mayer and Sims, 1994) are the only two variables evaluated. Mayer and Gallini (1990) found that individuals with low content domain knowledge benefit most from animation and narration, indicating that crystallized intelligence moderated the effect of multimedia principles on test performance. Mayer (2001) referred to his findings related to spatial ability and domain specificity as the individual difference principle. However, in all of the individual difference experiments, Mayer and colleagues evaluated performance in the animation and narration condition. No results have been published that test Mayer's initial findings, using all three multimedia conditions, against key cognitive individual difference variables.

Method

Participants. One hundred thirty-two Texas Tech University undergraduate students (75 females and 57 males) enrolled in Human Sciences, Chemistry, Political Science, Mass Communications, and Education courses, completed the two-hour experiment in exchange for extra credit toward an exam score.[10] Sets of experimental sessions were held for all the students at various times to accommodate student schedules.[11]

Materials. In order to administer the MMCB to large groups, Stalcup and Maki (2002) converted the MMCB materials to an electronically delivered format. The textual stories and questions for all six stories were entered into a Microsoft PowerPoint format.

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[10] Faculty from each major college were contacted and asked to offer their students extra credit for participation in the study. Careful analysis and collaboration with faculty ensured that extra credit opportunities were similar across courses. In all cases, students receive points toward a previous or upcoming examination in the course. None of the students were required to attend.

[11] Each class received a personal visit and students were invited to participate. The professor announced the extra credit opportunity and students signed up for one of the nine sessions.

The slide transition feature controls line speed and question exposure in exact accordance with specifications reported by Gernsbacher and Varner (1988). The original 35mm slides for the pictorial stories were digitized and each image was imported into PowerPoint as a separate screen shot. In compliance with the procedure used by Gernsbacher, et al. (1990), the two textual stories included 636 and 585 words, respectively, and were presented at 185 words per minute. The two auditory stories were comprised of 958 and 901 words and were presented at 215 words per minute. The two pictorial stories were composed of 31 and 32 pictures with an exposure time of 7.75 seconds per picture. Gernsbacher's (1997) initial multi-media comprehension test format was free recall; students read questions and were asked to include as much detail as they could recall in their answers.

Gernsbacher later derived a multiple-choice test version for the textual and auditory stories. Based on Gernsbacher's specific and elaborate scoring instructions that accompany each test, Stalcup and Maki (2002) generated multiple-choice tests for the pictorial stories based on the correct response information from the free recall scoring information. In comparing the multiple choice versions for the auditory and verbal stories with the free recall answers for those stories, Stalcup and Maki (2002) noted that Gernsbacher selected common wrong answers from the free recall as options for the multiple-choice questions. As such, incorrect answers from the free recall scoring sheets served as answer alternatives in the recognition, multiple-choice version of the test for the pictorial stories. The multiple-choice test and associated scoring information for the pictorial stories are reported in Appendix B, "Hiram's Red Shirt" and "Old MacDonald's

Apartment House". Recognition scoring for the textual and auditory stories is reported on the University of Wisconsin Language Lab World Wide Web site at http://psych.wisc.edu/lang/materials/CompBat.html

Given that previous research found that the recognition form of assessment yielded the same intercorrelations as the free recall form, the recognition form of the MMCB is a feasible alternative to the free recall form. The recognition form requires far less overhead in term of rater time and data entry. MMCB stories can be assessed with a computer-based recognition assessment so that the data are collected directly into a database, minimizing human error. In order to measure multimedia comprehension skill, participants completed the MMCB and a multiple-choice test after each story.

In order to measure working memory capacity, participants completed the automated version of an OSPAN working memory test (Engle, 2003). The subject is presented with a dual task, typically word recognition and simple mathematical computation. The OSPAN test required the participant to solve a simple mathematical equation mentally and either confirm or deny the answer appearing on the screen. A word appeared at the end of the equation and answer; the task goal was to remember the words at the end of each equation/answer set. As such, the individual performed the math calculation and simultaneously remembered a word presented immediately after the math operation. After a series of several computations, the subject must recall the words presented. Cantor and Engle (1993) argued that high-span individuals have a heightened ability to suppress task-irrelevant information--the mathematical answers in this instance. The number of total words recalled served as a measure of working memory capacity.

As a measure of fluid intelligence, participants completed Raven's Progressive Matrices (RMI). Developed in 1960, RMI is an instrument reported to be a reliable and valid measure of fluid intelligence (Ackerman, Beier, & Bowen, 2002). College entrance exam scores were used as a second measure of fluid intelligence. Longstreth, Walsh, and Alcorn (1986) found that college entrance exam scores correlated highly with general intelligence, indicating that the SAT scores include some measure of fluid abilities.

Procedure. Participants were seated and asked to read and complete a consent form. Each session included one Mayer multimedia condition, the MMCB, the automated OSPAN, and the RMI (short version). Order was counterbalanced and the Mayer multimedia condition was randomly assigned to each session. The multimedia learning conditions were administered and scored exactly as in Experiment 1. For the MMCB, each participant completed the six computer-based stories previously described, with a short multiple-choice test following each story. For the RMI administration, participants were given a practice test and five minutes to review the questions. After the five minute review, the experimenter selected one of the practice questions and asked the group for the answer. The RMI task goal was reiterated; the object of the task was to identify the correct missing piece, based on the pattern of the figure. After collecting the practice booklets, participants received the short version of the RMI and were given twenty minutes to complete as many questions, as accurately as possible. For the automated OSPAN, participants clicked on an executable file that administered the OSPAN test, previously described. Participants provided answers using the mouse and keyboard as input devices. After the completion of all four experiment components, participants were de-briefed and the associated faculty notified of their participation.

Results

Experiment 2 was designed to measure the impact of working memory, fluid intelligence, multimedia comprehension skill, and multimedia learning condition assignment on transfer test performance. Analyses indicated a main effect of each cognitive individual difference variable on transfer test scores, but no interaction between multimedia condition assignment and each cognitive ability measure. The modality and redundancy effects persisted beyond the extraction of variance due to cognitive individual differences.

Table 3 displays the means and standard deviations for the cognitive individual variables and the multimedia condition (omnibus descriptive statistics).

Table 3. Experiment 2: Descriptive statistics for cognitive ability measures

Measure	N	Mean	Standard Deviation
Total OSPAN	132	55.92	12.94
MMCB Total	132	43.48	7.78
RMI- # Correct	132	19.10	4.87
MM Score	132	2.65	1.54
SAT/ACT Z-score	132	.91	

Note that the MMCB total score included the summation of textual, auditory, and pictorial stories. The current study replicated the overall pattern shown by Gernbacher, Varner, and Faust (1990). The MMCB means and standard deviations by test type are reported in Table 4.

Table 4. Experiment 2: Correlation matrix for cognitive ability measures

	Total OSPAN	MMCB Total	RMI - # Correct	MM Score	SAT/ACT Z-score
Total OSPAN	1	.22*	.40**	.23**	.47**
MMCB Total		1	.47**	.23**	.37**
RMI # Correct			1	.31**	.60**
MM Score				1	.42**
SAT/ACT Z-score					1

* Correlation is significant at the .05 level
** Correlation is significant at the .01 level

In terms of the relationship among the MMCB story scores, the correlation between written/textual and auditory was .51; the correlation between written/textual and pictorial was .55; and the correlation between auditory and pictorial was .53 (all correlations were significant at the .001 level). As with previous research, a simultaneous regression analysis revealed that MMCB comprehension scores accounted for 13.6% of the variance in SAT scores, which represented a significant portion of the variance $F(1,130)=20.93$, $MSE=2.32$, $p<.001$. A maximum likelihood exploratory factor analysis yielded one common factor, replicating Gernsbacher, et al. results (1990). The general comprehension factor yielded an eigenvalue of 2.05 accounting for 68.45% of the common variance among textual/written, auditory, and pictorial comprehension scores. The next eigenvalue for two factors was .49 followed by .44 for three factors. The factor analysis supports the use of total MMCB score in the remaining analyses.

As with Experiment 1 and displayed in Table 5, mean differences and standard deviations indicated a replication of previous research.

Table 5. Experiment 2: Descriptive statistics and comparison of CTML multimedia conditions

Condition	N	Mean	Standard Deviation
Animation & Text (AT)	46	2.32	1.32
Animation, Narration, & Text (ANT)	39	1.89	1.34
Animation & Narration (AN)	47	3.50	1.45

Comparison	t	df	p
AN/ANT	5.61	84	.00
AN/AT	4.42	91	.00
ANT/AT	1.48	83	.14

An analysis of variance indicates multimedia group differences beyond chance occurrence $F(2,129)=18.30$, $MSE=1.89$, $p<.001$. Two-tailed t-test analyses between the animation and text (AT) group and the animation and narration (AN) group (modality principle) revealed that AN scores were higher than AT scores $t(91)=4.42$, $p<.001$. In terms of the redundancy principle, two-tailed t-test analyses between the animation, narration, and text (ANT) and the AN group revealed that AN scores were higher than ANT scores $t(84)=5.61$, $p<.001$. Replicated from Experiment 1, two-tailed analyses between animation, text, and narration (ANT) and animation and text (AT) indicated that there was no significant difference between the two conditions, $t(83)=1.48$, $p=.14$.

To examine the predictive validity of the cognitive ability variables and multimedia condition, a simultaneous regression analysis with total OSPAN score, total MMCB score, RMI score (number correct), and multimedia condition assignment (two terms contrast coded; the ANT and AT condition compared to the AN condition, and the ANT condition compared to the AT condition) as predictors accounted for 35% of the variance in multimedia transfer test score $F(5,126)=13.60$, $MSE=1.61$, $p<.001$. Table 6 displays the standardized regression coefficients, which indicated that total OSPAN, total MMCB, RMI (number correct), and multimedia assignment contributed significantly to the explanation of variance in multimedia transfer test scores.

Table 6. Experiment 2: Model summary, standardized regression coefficients

Variable	Standardized Coefficient (Beta Weights)	t	Sig
Total OSPAN	.16	1.8	.05
Total MMCB	.17	1.8	.05
RMI	.19	2.2	.03
MM Condition Contrast 1 (AN, ANT & AT)	.48	6.6	.00
MM Condition Contrast 2 (ANT & AT)	-.11	-1.5	1.29

Note: All cognitive ability variables centered

With main effects confirmed for the cognitive ability measures and the condition assignment, separate hierarchical regression analyses were conducted for each cognitive variable, entering the contrast coded condition assignment and cognitive variable first, and then the interaction terms second.[12] Table 7 exhibits the model summary statistics, confirming the main effects of MMCB, Total OSPAN, and RMI on transfer test score and indicating no interaction between any cognitive variable and multimedia condition assignment (indicated in the model 2 row for each variable in Table 7).

[12] Note that all cognitive variables are centered and the interaction terms are the product of the centered cognitive individual difference variable and each contrast-coded condition. In the second step of each analysis, two interaction terms represented the possible interaction between the cognitive variable and multimedia condition assignment.

Table 7. Experiment 2: Interaction analyses; cognitive variable and multimedia condition

	Model	R Square	R Square Change	F Change	Sig F Change
MMCB	1	.29	.29	17.36	.00
	2	.30	.01	.92	.40
Total OSPAN	1	.28	.28	16.72	.00
	2	.30	.02	1.42	.25
RMI	1	.33	.32	19.77	.00
	2	.34	.02	1.97	.14

Analyses to this point indicated that both multimedia condition and cognitive individual differences significantly predicted transfer test score. To determine if multimedia condition predicts transfer test score beyond the variance accounted for by cognitive individual variables, hierarchical set regression was conducted; entering the cognitive individual differences first, as a priori variables, and multimedia condition assignment second. As noted earlier, 35% of the variance in transfer test score is accounted for by all variables, with cognitive individual variables explaining 11.9% of the variance $F(3,128)=5.78$, $MSE=2.15$, $p=.001$ and multimedia condition explaining 23.1% of the variance $F(5,126)=13.60$, $MSE=1.61$, $p<.001$ in transfer test scores. Results indicated that both cognitive individual differences and multimedia condition assignment predicted a significant portion of the variance in transfer test scores. The modality and redundancy effects persisted beyond the impact of cognitive individual differences.

CHAPTER V

EXPERIMENT 3 – TEXT POSITIONING

Based on results obtained in Experiment 2, some of the multimedia effect on transfer test score persisted after the variance associated with cognitive individual differences (working memory, multimedia comprehension skill, and fluid intelligence) were considered. Experiment 3 was designed to further explore the significance of display design, to see if the modality and redundancy effect are artifacts of display design, rather than a result of modality combination. From the direct theory of perception, Zhang offered five elements in the physical display: text, distance, shape, density, and position (1996, p. 62). Zhang (1996) contended that each element impacts information processing and perception. The human factors field of study has been examining human-computer relationships for decades (Nikolic, M., Orr, J.M., & Sarter, N.B., 2004). Physical attributes of the display have been identified as fundamental in examining the effectiveness of the design (Sanders & McCormick, 1993). In addition to screen elements, element organization was paramount to effective display design. Organization included the precepts of grouping, space, sequence, complexity, and consistency (Ozok & Salvendy, 2000; Sanders & McCormick, 1993). By manipulating these organizational elements, one can impact the effectiveness of the display design.

Three basic constructs depict the possible relationships between text and graphics: the split display (text and graphics displayed on separate portions of the screen), the integrated display (the text and graphics are part of the same display), and the pop-up display (the text information is integrated in the graphics using pop-up fields, which require user intervention to appear) (Betrancourt & Bisseret, 1998). Betrancourt and Bisseret (1998) found that the integrated displayed yielded superior information recall and retention. Aspillaga (1991) reported that text location close to the relevant graphic facilitated learning. As such, previous research suggested that text and graphics should be contiguous. The CTML posited a contiguity principle, suggesting that the display effectiveness in multimedia learning lessons increased when words and pictures were presented contiguously in time or space, even though his lightning materials contained text that scrolls at the bottom of the screen, separate from the animation (Mayer & Anderson, 1992). However, previous research did not apply the contiguity principles to the evaluation of the modality and redundancy principles.

The body of research on the cognitive theory of multimedia experimentally addressed a few key display design issues relevant to the current experiment. For instance, Mayer, Farmer, and Campbell (2004) demonstrated that students receiving personalized text scored higher on transfer tests compared to non-personalized text. Personalized text included less formal text using conversational tone, compared to formal, third-person style. For an example, see Appendix A for the lightning module text written in a conversational style. Moreno and Mayer (2000, 2004) reported that students receiving personalized text in a computer problem-solving game scored higher on retention and transfer tests compared to those receiving third person monologue text. Additional media manipulations further clarified the relationship between animation and narration and transfer test scores: presence of a personalized software agent that "lectures" the learning module (Craig, Gholson, & Driscoll, 2002; Mayer, Dow, &

Mayer, 2003); animation voice characteristics and social cues (Mayer, Sobko, & Mautone, 2003); pre-training (Mayer, Mathias, & Wetzell, 2002); and graphic text organizers (Nilsson & Mayer, 2002). Experiment 3 manipulated the location of text in the animation and text and the animation, text, and narration conditions.

Method

Participants. One hundred sixty-two participants (72 females and 90 males) were randomly assigned to a multimedia condition in exchange for course credit in lower-level History and Mass Communications courses. Experiment 3 was conducted in a university Windows-based computing lab with 18 available workstations. All participants reported normal hearing ability. Each session was randomly assigned one of the six multimedia conditions (AN, ANT, ANT2 - text repositioned, AT, AT2 – text repositioned, and NT).

Materials. Previous research using lightning module lesson positioned the text at the bottom of each frame (See Appendix B for illustrations). The aforementioned research suggested that an integrated design would be more effective, as the text and pictures are closer together and can be simultaneously viewed. The initial Animation and Text (AT) condition was altered; the text was moved immediately next to the animation, with all other aspects of the lesson remaining the same. Figure 3 compares an initial multimedia lightning screen shot to the lightning materials redesigned for Experiment 3.

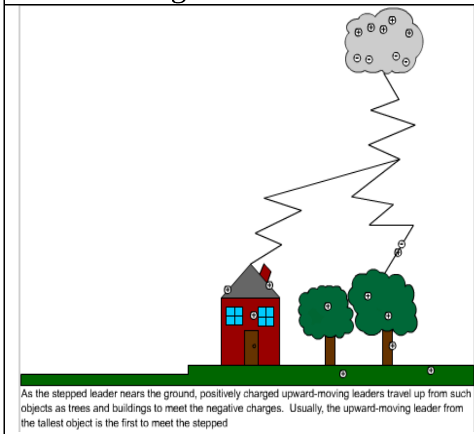
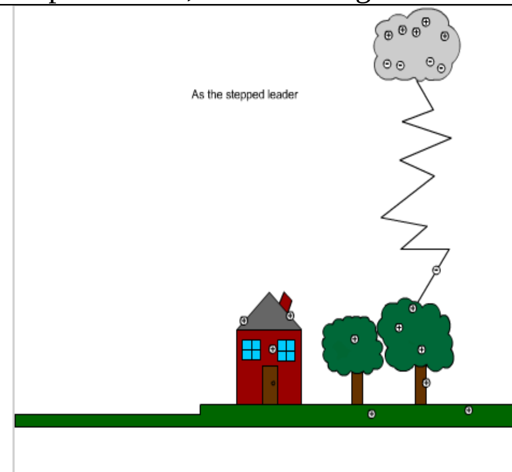
<table>
<tr><th>Original lightning lesson material format; text scrolling at the bottom of the screen</th><th>Text re-positioned lightning lesson format in Experiment 3; text scrolling</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 3. Experiment 3 Lightning lesson compared to initial lightning lesson

The Animation, Narration, and Text (ANT) condition was altered in the same manner (See Appendix B), with all other lesson aspects unchanged. In addition, a narration and text condition was created, which completes all logical combinations, as previously noted as absent in previous research.

Procedure. After all participants were seated, they were instructed that they would experience a short multimedia lesson, followed by a brief test. Regardless of multimedia assignment, all participants wore headsets and were told that their presentation may or may not include audio, text, and pictorial information. All procedural aspects of Experiment 3 were identical to Experiment 1. Exactly as in Experiments 1 and 2, a transfer test was administered with paper and pen; participants were allotted ten minutes to complete the transfer test, as previous research specified (Mayer, 2001). The test was comprised of four questions: a redesign question, a troubleshooting question, a prediction question, and a conceptual question (Table 1).

Tests were collected and participants briefed on the nature of the study. The scoring procedure was identical to the process deployed in Experiment 1.

Results

Results indicated that text repositioning removed the significant difference in transfer test scores between the animation and text condition and the animation and narration condition, but significant mean differences in transfer test scores remained between the animation, text, and narration condition and the animation and narration condition. Repositioning the text eliminated the modality effect, but not the redundancy effect. Additionally, analyses indicated a significant difference in transfer test scores between the animation and narration condition and the narration and text condition. Students performed significantly better in the animation and narration condition compared to the narration and text condition.

Table 8 exhibits the descriptive statistics for the multimedia conditions.

Table 8. Experiment 3: Descriptive statistics and comparison of multimedia conditions

Condition	N	Mean	Standard Deviation
Animation & Narration (AN)	28	4.24	1.22
Animation & Text (AT)	25	1.88	1.15
Animation & Repositioned Text (AT2)	33	3.72	1.47
Animation, Narration, & Text (ANT)	28	2.20	1.04
Animation, Narration, & Repositioned Text (ANT2)	20	3.35	1.43
Narration & Text (NT)	28	2.70	1.34

To test for a main effect of text positioning, a 2 (modality combination; ANT – redundancy principle, AT – modality principle) X 2 (text positioning, separated or contiguous) ANOVA revealed no main effect of modality combination F(1, 157)=.010, MSE=1.86, p=.921; a main effect of text positioning F(1,157)=30.907, MSE=1.86, p<.001; and no interaction F(1,157)=3.02, MSE=1.86, p=.204. To investigate the main effect of text positioning further, pairwise comparisons revealed a significant mean difference between the original redundancy condition (ANT) and the text re-positioned redundancy condition (ANT2) , t(46)=3.24, p<.01 and the original modality condition (AT) and the text repositioned modality condition (AT2) revealed no significant mean difference t(56)=5.16, p<.001. However, when compared to the animation and narration condition (AN), pairwise comparisons yielded a significant mean difference for the AN/ANT2 condition t(46)=2.33, p<.05 but not for the AN/AT2 condition t(59)=1.49, p=.142.

Table 9 exhibits the set of pairwise comparisons conducted; note that test performance mean difference between the narration and text condition (NT) and the animation and narration condition was significant t(54)=4.50, p <.001, indicating superior transfer test scores in the AN condition (*m*=4.24) compared to the NT condition (*M*=2.70).

Table 9. Experiment 3: Pairwise mean comparisons for multimedia conditions

Comparison	t	df	p
AN/ANT	6.74	54	.00
AN/AT	7.21	51	.00
AN/ANT2	2.33	46	.03
AN/AT2	1.50	59	.14
AN/NT	4.50	54	.00
ANT/ANT2	3.24	46	.00
ANT2/AT2	.89	51	.38

Pairwise comparisons indicated that text repositioning removed the modality effect in the animation and text condition, but not in the redundancy effect in the animation, text, and narration condition. Participants in the animation, text, and narration (text repositioned) condition still performed lower on transfer score tests compared to the animation and narration condition, but participants in the animation and text (text repositioned) condition performed no differently on the transfer test compared to the animation and narration condition. Encouraged that display design components impacted transfer test performance and partially removed findings from previous research (the animation and narration condition yielded superior test performance), Experiment 4 manipulated another important display design feature.

CHAPTER VI

EXPERIMENT 4 – MOTION AS A DISTRACTER

The lightning modules contained text that scrolled across the bottom of each screen (See Appendix B). In the animation, narration, and text (ANT) condition, word motion was synchronized with the spoken text. The display presented auditorily and textually at the same time. In addition to text movement, participants in the ANT condition are also exposed to movement in the animated display. Abrams and Christ (2003) found that motion onset in a computerized display, with participants identifying targets among other targets and distracters, captured attention regardless of the information provided in the moving target. This finding is theoretically congruent with the ecological approach to perception discussed previously. If our perceptual system is wired to pick up information from an optical array, then movement, which introduces new information with each change, would be an important aspect of the environment to consider in terms of attentional capture. It follows that when the environment is a computer-based display, then any object motion may create a distraction to the participant.

Previous research on reading in a computerized display indicated that text and animation movement can distract from information processing. Aaronson and Colet (1997) found that, among other attributes measured, text movement (successive left-to-right) interfered with linguistic processing in computerized mathematical word problems. The interference translated into greater processing time requirements and reduced accuracy (Aaronson & Colet, 1997). Speelman (1998) reported degradation in achievement test performance when participants read animated text compared to static text and concluded that test motion makes reading from a computerized display more difficult compared to static text. In terms of non-textual object movement associated with static text, Bolivar and Barresi (1995) designed animated and static geometric figures, coupled with static text describing the movement and an associated mathematical principle. After viewing the animated display, participants completed a simple retention test; results indicated that the motion in the animation received more attention compared to the stationary object (Bolivar & Barresi, 1995). To examine the underlying components of multi-sensory movement, Beer and Roder (2004) designed materials that included sounds and moving objects (dot patterns). They reported that attending to object motion effects processing within each modality and across modalities; the nature of the effect depends on the task goal and experimental manipulation (Beer & Roder, 2004). Relevant in the present research is that object motion attracts attention. Moving text and moving objects are likely to distract participants, both with respect to processing text/picture and auditory stimuli. Soto-Faraco and Spence (2004) reported that, "our perception of stimulus movement in one modality is frequently, and unavoidably, modulated by the concurrent movement of stimuli in other sensory modalities (p. 29)."

However, a burgeoning body of physiological research challenges the effect of cross-modal motion on perception. Tsujimoto and Tayama (2004) designed materials that included both motion and color displays, with an accuracy performance test following each trial. They found that performance on motion and color accuracy was independent and suggested that, "dividing attention between motion and color involves independent mechanisms (Tsujimoto and Tayama, 2004, p. 237)." As such, processing in one mechanism did not necessarily impact processing with another mechanism. Soto-Faraco and Spence (2004) noted that neuroimaging research confirmed the presence of both modality-specific processing areas and cross-modality processing areas within the brain. Similary, Derrington, Allen, and Delicato (2004) suggested that current physiological data indicated that the presence of both local, modality-specific sensors and global, cross-modal sensors were important in the early perception of two-dimensional motion.

In terms of the present research, the impact of display motion, both textual and pictorial, may be impacting perception and distracting attention, which would account for the lower transfer test performance in the redundant condition (ANT) compared to the animation and narration condition. Experiment 4 removes the textual motion in the redundant condition to evaluate the impact on transfer test performance compared to the animation and narration condition. Note that the motion in the animation is a key part of the material design and cannot be removed without confounding the amount of information displayed with multimedia condition assignment, but that the text motion does not add substantively to the multimedia learning message.

Method

Participants. Ninety-one participants (34 females and 57 males) were randomly assigned to a multimedia condition in exchange for course credit in lower-level History and Mass Communications courses. Experiments were conducted in a university

Windows-based computing lab with 18 available workstations. All participants reported normal hearing ability.

Materials. A new condition was designed, removing the text motion from the redundant condition. The AN, ANT, and ANT2 (text-repositioned) condition remained the same as in Experiment 3. Figure 4 illustrates the materials used in Experiment 4.

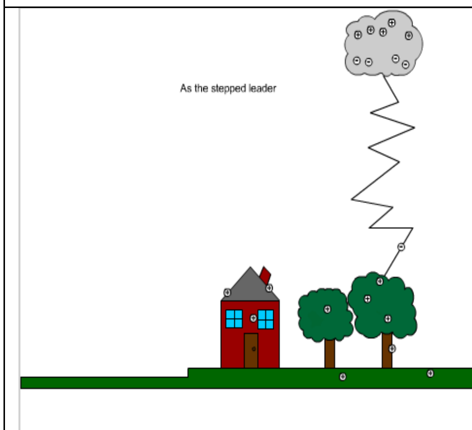
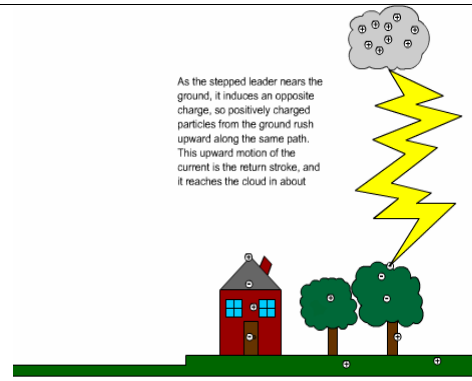
Experiment 3 lightning lesson format (text re-positioned):	Experiment 4 lightning lesson format (text re-positioned and text motion removed; text introduced in blocks of static words)
	

Figure 4: Experiment 4 Lightning lesson compared to Experiment 3 lightning lesson

Each session was randomly assigned one of the four multimedia conditions (AN, ANT, ANT2 - text repositioned, ANT3 – text repositioned and motion removed).

Procedure. After all participants were seated, they were instructed that they would experience a short multimedia lesson, followed by a brief test. Regardless of multimedia assignment all participants wore headsets and were told that their presentation may or may not include audio, text, and pictorial information. Procedural administration of the multimedia learning modules was exactly as in Experiment 1. A transfer test was administered with paper and pen as in Experiments 1, 2, and 3; participants were allotted ten minutes to complete the transfer test, previous research specified (Mayer, 2001). The content transfer test used in Experiment 4 is the exact test administered in Experiments 1, 2, and 3. Tests were collected and participants briefed on the nature of the study.

Results

Results confirmed that text repositioning removed the significant difference in transfer test scores between the animation and text repositioned condition and the animation and narration condition. In addition, eliminating text movement removed the significant difference in transfer test performance between the animation and narration condition and the animation, narration, and text condition. The elimination of text motion eradicated the redundancy effect. Experiment 4 found no significant difference in transfer test scores between the animation and text repositioned condition or the animation, motionless text, and narration condition. Display design manipulations removed the superiority of the animation and text condition with respect to transfer test performance.

Table 10 displays the descriptive statistics for the four multimedia conditions.

Table 10. Experiment 4: Descriptive statistics and comparison of multimedia conditions

Condition	N	Mean	Standard Deviation
AN	26	4.23	1.24
ANT	21	2.17	.89
ANT2	17	3.07	.85
ANT3 (No Text Motion)	27	4.49	1.43

Pairwise comparison once again replicated Mayer's (2001) initial redundancy principle $t(45)=6.41$, $p<.001$, indicating that the animation and narration condition participants performed higher on the transfer test compared to participants in the animation, narration, and text condition. A comparison between the animation condition and the animation, narration, and text-reposition condition replicated the findings in Experiment 3, t(41)=3.84, p<.001, indicating that participants in the animation and narration condition outperformed participants in the animation, narration, and text-repositioned condition on the transfer test. The comparison between the animation and narration condition (AN) and the animation, narration, and static text-repositioned condition (ANT3) indicated no significant mean difference transfer score for each condition, t(51)=.707, p=.483. Once the text was repositioned and the text motion removed, the difference between the animation and narration combination and the animation, narration, and text combination was removed. With the application of a key display design principle, the superiority of the animation and narration condition on transfer test performance to the animation, narration, and text condition was removed. Results indicated that display design techniques and not modality combination accounted for the difference in transfer test performance.

CHAPTER VII

GENERAL DISCUSSION

Cognitive psychologists must rigorously test the CTML and examine the limitations of the principles and the conditions under which the theory and principles do and do not apply. Present research suggested that the theory is vulnerable in terms of its overly simplistic view of information processing, inadequate attention to working memory, incomplete consideration of attentional mechanisms, and incomplete attention to experimental design and method. The present research replicated previous research and proceeded to tease apart components of the theory and operational aspects of the experimental design. Experiment 2 yielded evidence that cognitive individual differences accounted for significant variance in multimedia transfer scores, but that multimedia condition assignment still accounted for unique variance in transfer test scores, beyond individual cognitive differences. Thus, working memory, multimedia comprehension skill, and fluid intelligence were relevant individual differences that affected transfer learning, but the impact of multimedia condition assignment remained a predictor of transfer learning. Motivated by display design research and previous research on text placement, Experiment 3 manipulated the position of text in the animation and text (AT) condition and the animation, narration, and text (ANT) condition. Text was relocated from the bottom of the screen to a block immediately next to the animation. Results indicated that text relocation removed the difference between transfer test performance in the animation and text (AT2) compared to the animation and narration (AN) condition, but the difference between the AN condition and the animation, narration, and text

(ANT2) condition persisted. Motivated by research on display motion and associated impact on perception and attention, Experiment 4 removed the motion associated with the scrolling text in the animation, narration, and text condition. The manipulation in Experiment 4 removed the remaining transfer test performance advantage of the animation and narration condition.

The present set of experiments challenges the modality and redundancy principles associated with the Cognitive Theory of Multimedia (Mayer, 2001). While cognitive individual differences contributed to the variance in transfer test scores, the present research suggests that display design attributes were responsible for the effects, not multimedia combination. The current research indicates that text positioning and motion distracted from comprehension and processing in the multimedia conditions, which accounted for the difference in transfer test performance. In essence, evidence indicates that there is no "magic bullet" combination of multimedia that inherently yields superior transfer learning. Further research is needed to elicit display design characteristics that are particularly relevant with computerized learning materials. Norman (1998) suggested that a focus on isolating elements that complicate computerized display is a key component of enhancing usability. In addition, physiological perception research is likely to shed additional light on the topic as issues of color and motion are investigated further.

In terms of the cognitive aspects of multimedia learning, further research is needed to examine the differences between learning expository text and narrative text. While both expository and narrative texts use the same general cognitive structures, Van den Broek, Virtue, Everson, Tzeng, and Sung (2002) contended that "narrative texts possess a causal-temporal structure that is often more familiar to readers than the logical structure of expository texts" (pp. 149). Van den Broek et al. (2002) also noted that expository texts, while widespread in our society, are still a subset of the reading material encountered by most people. Anderson (2000) illustrated a similar comparison, differentiating declarative (knowledge of facts) and procedural (knowledge of processes) knowledge. Narrative texts may pose a different paradigm and challenge for instructional technology application compared to expository texts.

With the current demand for distance learning and the integration of technology and learning, the efficacy of multimedia-delivered narrative learning modules is a question to be empirically addressed. In many secondary and higher education courses and in certain content domains, narrative text comprehension is a critical component for learning (Combs, 1997). Van den Broek (1994) suggested that the ability to make accurate inferences is an important aspect of narrative comprehension. Van den Broek (1994) argued that the challenge with narrative texts is the accurate mental representation of the structural relationships illustrated in the narrative texts. He contended that structural relationships can be segmented into four primary categories: anaphoric relations "provide identity, by establishing that a person or object in one clause or sentence is identical to that in another clause"; causal relations "establish that the event described in one clause causes the event in a second clause"; instrument inferences "activate the tools or methods that are used in events described in the text"; and thematic or global relations "provide a cohesive context and theme to the narrative text" (Van den

Broek, 1994, p. 541). Stine-Morrow, Soederberg-Miller, and Leno (2001) found that attention to narrative structure facilitated memory for the text. The current academic climate necessitates further research on the efficacy of multimedia- delivered narrative and expository texts.

CHAPTER VIII

CONCLUSION

The proliferation of technology-enhanced learning materials has engendered a plethora of research on the efficacy of such materials, in an effort to create guidelines for educators. The present research suggests that any prescriptive guidelines warrant serious scientific evaluation before claiming to optimize learning. Sternberg (1988) suggested that factors other than ability are critical to student performance. Clearly, both individual cognitive abilities and display elements contribute to electronic learning, but the relationship and components have not been tested enough to devise a simple set of practical guidelines for educators. Further research must address display design issues within the specific learning context. Evidence to date does not provide hope that the scientific community is close to such a set of recommendation and guidelines. If anything, physiological, HCI, attention, and perception research indicates that we are far from a "magic bullet" theory of multimedia learning.

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APPENDIX A

EXPANDED LITERATURE REVIEW AND HISTORICAL FOUNDATIONS: HCI DESIGN PRINCIPLES

Display Significance

In assessing the importance of computerized multimedia modules, it is clear that the perception of the display is of paramount importance. The direct theory of perception offered the first argument to suggest that the display design has a significant role in any computerized lesson. In a revolutionary and controversial approach to perception, Gibson (1979) argued that perception is not based on neural stimulation contingent on a retinal image, but on information pick up from the optic array. He argued that all of the information necessary for perception can be found in the sea of physical energy that includes substances, media, and surfaces (Gibson, pp. 1-4). The ambient light reaching our eyes is rich in pattern and change; Gibson suggested that we register the invariants of the changing structure to determine our perception (pp. 52-64). This environmental approach to perception suggested that we have a perceptual system made up of various organs that all contribute to perception (pp. 238-255). One relevant conclusion that Gibson posited is that we see what an object affords and the important measurement to consider is the dimensions of variation of form. (p. 197).

As an application of Gibsonian theory, representational display analysis contributed several points germane to display design. Displays consist of two types of information: the represented domain and the representing domain. (Zhang, 1996) The representing domain is the physical manifestation or information found in the optic array. Zhang concluded that any task analyzed must be designed with affordances of the medium in mind (Zhang, 1996, p. 71). In a later publication outlining the theoretical implications of direct perception, external representation, and problem solving, Zhang argued "external representations are defined as the knowledge and structure in the environment, as physical symbols, objects, or dimensions. . . and as external rules, constraints, or relations embedded in the physical configuration. . .The information in external representations can be picked up, analyzed, and processes by the perceptual systems alone. . ." (Zhang, 1997, p. 180). The display, as an external representation, can both obviate the need for internalization and prohibit the ability to internalize (Zhang, 1997).[13] Indeed, the ecologically based, direct perception theory substantiated the role and significance of the display design.

A second compelling argument originated from a computer science vantage point, and suggested that the interface is an independent means of communication in the internal input-output system (Norman, 1998; Sutcliffe, Ryan, Doubleday, & Springett, 2000). Engineers argued that a user-centered system design is the optimum approach to display design. Specifically, the direct manipulation approach to interface design suggested that two aspects of "directness" are critical: distance and engagement (Hutchins, Holland, & Norman, 1986). Most applicable here is the concept of interface and user distance. The "gulf of evaluation" indicated a unidirectional relationship

[13] By internalization, Zhang is referring to the transformation of external representation to internal representation, which he identifies as optional for perception. In this referenced article, he discusses the disparate cognitive approach, which suggests that internalization is necessary for perception.

between the physical system state and the goals of the user; and the "gulf of execution" indicated a second unidirectional relationship from the goals of the user to the physical system state. (Hutchins et al., 1986, p.94) Each gulf presents a gap, which prevented a user from goal attainment. For multimedia designers, the key was successful bridging the gap, fostering successful human-computer interaction. Norman (1986) explained that the gap from the goals to the physical system (gulf of execution) can be bridged by "intention formation, specifying the action sequence, executing the action, and. . . making contact with the input mechanisms of the interface" (p. 39). In essence, the user must have been able to implement task goals successfully. The gulf of evaluation required the user to interpret the system state and compare it to initial task goals and intended results. Norman (1986) explained that the gulf of evaluation can be bridged by "output displays of the interface, moving to the perceptual processing of those displays, to its interpretation, and. . . the comparison of the interpretation of system state with the original goals and intention" (p.41). According to this approach, the physical system and user are independently important components of interface design. While this theory described cognitive processing as a necessary part of display interpretation, the direct manipulation theory recognized the autonomous importance of the display in human-computer interactions.

The distributed information resources approach to human-computer interactions suggested a third case for display significance. Specifically, information structures present in the display support information-processing tasks (Wright, Fields, and Harrison, 2000). The theory postulated three forms of interface communication: information retrieval, comparison, and interaction. While this theory is more deeply intertwined with traditional cognitive theory stemming from connectionist networks and mapping, the resources model acknowledged that task success is partially display dependent. Various studies examined each type of interface communication and the role of display design. (Fields, Wright, & Harrison, 1997; Golightly & Gilmore, 1997; Howes & Payne, 1990) Wright, Fields, and Harrison concluded that, “our studies, by using versions that differed only in the resource representations, provide stronger evidence that the design of external resources is an important factor in determining interaction strategy” (2000, p. 35).

A final case for display significance emanated directly from traditional cognitive theory. Cognitive theory identified two types of cognitive load: intrinsic and extraneous. Relevant here is a brief discussion of extraneous cognitive load. Extraneous cognitive load has been defined as the “demand placed on working memory due to the manner in which the material is presented, and/or the activities required of the learner” (Niederhauser, Reynolds, Salmen, and Skolmoski, 2000, p. 250). As such, a poorly designed interface increased the demands on working memory, increased the summative cognitive load, and reduced learning. While this model required cognition for perception to occur, the approach supported the hypothesis that the display is a vital part of perception and information processing. These four eclectic areas of study offered the foundation for a theoretical justification for scientifically examining the role of display design in a hypertext environment.

Display Design

Physical attributes of the display are fundamental to examining the effectiveness of the design. Sanders and McCormick identified four physical attributes: polarity, character properties, density, and item organization (Sanders & McCormick, 1993). Polarity described the contrast between background and foreground. A higher degree of polarity was likely to heighten discernment. Specifically, polarity was critical when placing text against a background (Lippert, 1986). Character properties typically referred to the size and color of text on the screen. While accuracy and legibility standards dictated a character height equal to 11 or 12 minutes of visual angle, human factors engineers recommended a "slightly larger character size" for comfortable reading (Sanders & McCormick, 1993, p.113). In terms of text colors, the principles of polarity applied to the text as well. Additionally, few colors were better than many colors. Too many colors became a distraction in the display environment (Sanders and McCormick, 1993, p. 114). Density was "expressed in terms of the percentage of available character spaces being used" (Sanders & McCormick, 1993, p.114). As screen element density increased, search time and errors increased (Tullis, 1988).

A last physical attribute addressed by human factors engineers, and relevant here, was the organization of screen elements. Organization included the precepts of grouping, space, sequence, complexity, and consistency (Ozok & Salvendy, 2000; Sanders & McCormick, 1993). In essence, by manipulating these organizational elements, the effectiveness of the display design was impacted. For instance, physical inconsistency increased user errors in navigating the interface and increased time required for task completion (Ozok & Salvendy, 2000). Organization was a major determinant of display design efficacy, particularly the consistency of menu and navigation structures.

The study of language and linguistics offered a second contribution in defining display elements, an icon classification system. This field of research suggested that all icons can be classified as either textual (graphological, clause, or word) or pictorial (abstract or naturalistic) (Zammit, 2000). This classification suggested that the type of icon used to depict an operation or concept is critical was a display element worthy of further investigation. Ultimately, the physical representation inherent in the icon affected perception and interface navigation (Zammit, 2000). It is clear that display elements have been isolated and manipulated scientifically.

Another category of display properties was screen dimensionality. Elements in the screen display were configured to represent two-dimensionality or three-dimensionality. The sparse amount of investigation has yielded mixed results. One study found that a three-dimensional interface allowed for greater user efficiency and speed without compromising accuracy (Risden & Czerwinski, 2000). On the other hand, another group of scholars concluded that three-dimensional displays did not provide a significant design advantage over two-dimensional displays (Sutcliffe, Ennis, & Hu, 2000). Given that two-dimensionality may be an unrealistic representation of the information that we pick up from the environment, further investigation is required into the role of dimensionality in screen design.[14] In terms of the display, screen elements have been readily identified and isolated.

[14] For a detailed discussion of space and dimensionality in perception, refer to Gibson, 1979, pp. 147-150.

Additionally, Sanders and McCormick (1993) identified four physical attributes: polarity, character properties, density, and item organization. Polarity described the contrast between background and foreground. A higher degree of polarity was likely to heighten discernment. Specifically, polarity was critical when placing text against a background (Lippert, 1986). Character properties referred to the size and color of text on the screen. While accuracy and legibility standards dictated a character height equal to 11 or 12 minutes of visual angle, human factors engineers recommended a "slightly larger character size" for comfortable reading (Sanders & McCormick, 1993, p.113). In terms of text colors, the principles of polarity applied to the text as well. In essence, few colors were better than many colors. Too many colors became a distraction in the display environment (Sanders and McCormick, 1993, p. 114). Density was usually "expressed in terms of the percentage of available character spaces being used" (Sanders & McCormick, 1993, p.114). As screen element density increased, search time and errors increased (Tullis, 1988).

Human-computer interface research has contributed a plethora of display design research and recommendations for computerized display of information. These display recommendations must be considered in any computerized task, to include multimedia learning and online resource materials. Norman (1998) contended that failure to consider these design guidelines have resulted in complete interface design failure.

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APPENDIX B

EXPANDED LITERATURE REVIEW AND HISTORICAL FOUNDATIONS: THE ROLE OF ATTENTION IN DISPLAY DESIGN AND MULTIMEDIA DESIGN

Scholars have been debating the exact nature and dynamics of attention for over a century. Models of attention have largely focused on two distinct aspects of attention; perceptual processes and cognitive elements (Shiffrin & Grantham, 1974). Perceptual or systematic attention was usually held to be those interactions and reactions that occurred prior to attention. Cognitive elements involved higher order assimilations and decisions and, notwithstanding automaticity, involved attention. Systematic and cognitive responses have been widely examined within sensory modalities. For instance, Treisman and her colleagues debated for two decades about the manner in which our systematic visual coding works and at what point attention becomes a factor in visual processing (Duncan, 1984; Duncan, 1999; Duncan & Humphries, 1992; Treisman, 1992; Treisman, 1993). Treisman (1999) contended that feature selection is spatially based and processed pre-attentively, while feature integration requires focused attention. Duncan argued that the unit of perception is object based and that object files were retrieved and formed pre-attentively (Davis, 2001; Duncan, 1999). Similar investigations were conducted in the auditory (Dittman-Balcar, Thienel, & Schall, 1999; Hall, Pastore, Acker, & Huang, 2000; Linden, Grunewald, & Anderson, 1999) and tactile (Mahrer & Miles, 1999) modalities.

While examining the mechanics and neurology of intrasensory functioning contributed significantly to the body of scientific knowledge, the dominance of unimodal research created a distorted picture of reality for the scientific community. While isolating a modality might be more experimentally feasible, our everyday perceptual experiences typically involve multiple sensory input and output. Driver and Spence (1999) noted most situations are multimodal while most research is unimodal (p. 131). In the last thirty years, researchers have begun to formulate theory and empirically test postulates concerning multimodal sensory processing and crossmodal processing.

The complex nature of crossmodal investigations warrant a careful discussion of the main issues that have been identified and the associated theoretical paradigm in which the issue has been tested. The most elemental issues involved the relationship between modalities. For over a century, psychologists assumed that our sensory modalities were separate and distinct. For instance, George Berkeley in 1709 suggested, “If we take a close and accurate view of things, it must be acknowledged that we never see and feel one and the same object. That which is seen is one thing, and that which is felt is another. . . the objects of sight and touch are two distinct things” (Lederman & Abbott 1981 citing Berkeley, p.34). Similarly, Katz (Lederman & Abbott citing Katz, 1981) argued that touch and color are distinct entities offering independent input into our perception of the world. These early scholars fostered the modality-independent view of sensory modalities that has dominated scientific thought and investigation (Driver & Spence, 1999). Based on empiric work conducted in the last two decades, a second group emerged with a different outlook in terms of the relationship between modalities. This cohort of researchers contended that the functioning of each modality was largely independent, but that the modalities were linked by a physiological and cognitive mechanism (Driver & Spence, 1999; Macaluso, Frith & Driver, 2000; Rorden & Driver, 1999; Schmitt, Postma, & De Haan, 2000; Shimojo, S. & Shams, L., 2001; Spence & Driver, 1997).

A third federation of scientists contended that the sensory modalities were governed and regulated by a common physiological mechanism (McDonald & Ward, 2000; Martino & Marks, 2000). This integrative approach, referred to as the supra model, claimed that responses in one modality influence responses in other modalities due to a common regulatory device in the brain (Martino & Marks, 2000). In terms of the relationship between modalities, the linked and supra models challenged the reasoning and evaluation of the independent model proffered by Berkeley and Katz.

Psychologists wrestled with whether intermodal linking or coordination occurred pre-attentively or as a result of selected attention. Bertelson evaluated this theoretical issue by studying the ventriloquism illusion (Bertelson, 1999). Bertelson concludes that, "ventriloquism reflects a phenomenon of automatic crossmodal pairing; that is, formation of a crossmodal perceptual unit which takes place at a pre-conscious processing stage and thus must be clearly distinguished from conscious perceptual fusion" (Bertelson, 1999, p. 347). Further, Driver found that dynamic audiovisual integration influenced auditory selection pre-attentively (Driver and Spence, 1999). In an experiment designed by Driver and Spence (1999), participants heard two concurrent auditory messages involving three two-syllable words in random order, and the task was to report one of the messages and ignore the other message. No auditory information was used to cue identity of the target string or the distracter string. The relevant message was indicated visually. The participants viewed a presenter delivering a speech on a monitor and had to determine which of the two audio streams were congruent with the message the speaker was delivering. The sound emanated from a point nearby the monitor or a point farther away from the monitor. The results indicated that subjects display 17% better selective shadowing when visual sources were away from the speaker. Driver concluded that ". . .(this benefit) . . .implies that selective shadowing can be objectively improved by an illusory spatial separation between target and distracter sound. . .The implication. . .is therefore that some cross-modal integration can take place between audition and vision before auditory spatial selection is fully completed (Driver & Spence, 1999, p. 146)." With respect to the issue of pre-attentive versus selective attention, at least a part of crossmodal interaction occurred pre-attentively. Driver and Spence cited a host of animal and neurophysiological studies indicating that selective movement in one modality impacted other modalities (Driver and Spence, 1999).

A second aspect relevant to the role of attention was the source of activating attention. Two distinct forms of attention have been acknowledged: exogenous and endogenous. Exogenous attention was reported to be quick and almost automatic (Yantis & Jonides, 1990). Endogenous attention was thought to be "consciously controlled and relatively slow" (Schmitt et al., 2000). When subjects were cued exogenously, a target was presented and an external stimulus cued the subject in the sensory modality the investigator was scrutinizing. In most cases, the external cue caused an overt shift in attention in one sensory modality, accompanied by a concomitant shift in another sensory modality (Driver & Spence, 1999). In fact, Driver and Spence have repeatedly demonstrated this phenomenon with vision, audition, and touch in an elevation discrimination task concluding that exogenous cues lower response time compared to endogenous cues (Spence & Driver, 1994, Spence & Driver, 1996, Spence & Driver, 1997).

When subjects were cued endogenously, a symbolic cue was presented to engage cognitively directed decision-making and expectancy (Schmitt et al., 2000). Spence and Driver found that when strong expectations about the likely location of the target exist, attention shifted in the same direction for all modalities (Spence & Driver, 1997). Posner (1980) reported that while cued response time was always faster than uncued response time, the pattern reversed for exogenously cued trials after 200 milliseconds, commonly referred to as an inhibition of return. However, endogenous orienting has not produced the inhibition of return effect (Schmitt et al., 2000). Spence & Nicholls (2001) also documented that people take longer to shift away from tactile endogenous and exogenous cues. Even as early as 1977, Boulter conducted experiments and concluded that endogenous cueing increased response time and that any uncertainty required selective processing, which increased response time.[15]

A last relevant attentional issue is the cross relationship between modality and attention. Many have investigated the notion of attentional capacity within a single

[15] The authors also note that even with endogenous cueing, response time can be improved with practice, which increases the expectancy. They confirmed this conclusion with both a between group and within group experimental design.

sensory modality (Proctor & Proctor, 1979; Theeuwes, Kramer, & Atchley, 1999). Two groups of researchers have examined attentional capacity with respect to multiple sensory modalities. Duncan, Martens, and Ward (1996) concluded that attentional capacity is restricted within modality but not between modality. Similarly, in Experiment 2, Schmitt et al. (2000) suggested that it is important whether the attentional system was activated within a modality or between modalities. The issue of crossmodal attentional capacity is a new and further research is needed before generalizations and applications to multimedia learning modules can be made.

Key Research Areas

Although crossmodal attention sparked interest in recent years, many of the investigators interested in the topic are prolific. Four areas have been selected to discuss detailed empiric work as a representation of scholarly effort in this area and specific topics under evaluation: Cueing spatial location, the missing link, synesthetic (vision and touch) correspondence, and expectancy.

The Basics: Cueing Spatial Location. As an example of a typical study on crossmodal sensory input and attention, Buchtel and Butter (1988) conducted two experiments to test "the effects of spatial cues on speed of reaction to target stimuli in the same and different modalities" (p. 499). Experiment 1 tested the effects of visual and auditory spatial cues on response time (RT) to visual stimuli. Subjects sat in a sound-attenuated room and faced a projection screen. Visual targets were provided by two red light emitting diodes (LED); one at the right of the screen and one at the left of the screen. The visual cues were four LED's arranged in a square pattern around each of the visual targets. The auditory cue was a burst of white noise from two small speakers located behind the screen. Fixation point was a dot in the middle of the two target locations. Ten male subjects participated in one practice session and four order-counterbalanced sessions of 696 trials. Each subject completed two blocks with the visual cues and two blocks with the auditory cues. The time between the onset of the cue and the target was randomly presented at 50, 150, 400 and 1000 msec intervals. The subjects released a switch when they detected the target. On 80% of the trials the cue was presented on the same side as the target (valid cue) and on 20% of the trials the cue was presented on the opposite side of the target (invalid cue). Subjects were instructed to respond as quickly as possible by releasing the switch and to expect the target to appear predominately on the side that the single cue appeared.

Buchtel and Butter (1988) analyzed the data with visual and auditory cue order as a between subjects variable and cue modality, cue validity, stimulus onset asynchrony (SOA), and field in which the target was presented as within subjects variables. As expected, response times on valid cue trials were shorter than invalid cue trials. SOA had a larger effect on performance with the visual cue and a smaller effect on performance with the auditory cue. The results confirmed the hypothesis that a "non-spatial cue, in this case an auditory cue, would be as effective as a visual spatial cue in shifting attention to a visual target" (p. 504). Response times associated with the auditory cues were faster than with the visual cues. The authors suggested that the auditory cue may have had a more dramatic alerting impact on subjects than the visual cue. They found a greater response time decrement from 50-150 ms. associated with the visual cue, compared to the decrement associated with the auditory cue. A tenable explanation was that the auditory system is more efficient and rapid at processing alerting effects compared to the visual system.

In Experiment 2, the researchers compared the same spatial cues on response time to auditory stimulus. Experiment two was conducted with the same apparatus and design as Experiment 1 with the targets now auditory rather than visual. With eight male subjects participating in the trials, they found no significant cue validity effect, but did find a significant cue modality effect, with visual cue response time consistently shorter than response time on auditory cues. The side of the target or field effect indicated that leftward auditory targets had a faster response time compared to rightward auditory targets. Results suggested that faster spatial processing of an auditory stimulus occurred in the right hemisphere. The authors further concluded that, "the same visual and auditory cues that led to costs and benefits when the target was visual (Experiment 1) were totally ineffective when the target was auditory" (p. 507). Hence, the researchers found that cues presented in a modality different from the target were not as effective as a cue presented in the same modality as the target, in terms of covertly shifting attention. Research suggested that crossmodal cueing of spatial locations works only with modalities in which physical movement leads to improved sensory information, such as eye saccades. The Buchtel and Butter (1988) study was typical of the initial types of crossmodal investigations that have addressed crossmodal cueing of spatial location.

The Missing Link. As the research evolved, the asymmetry noted in the previous study continued to be debated, described, and delineated empirically. In 1994, Ward found that spatially irrelevant visual cues orient auditory attention, but spatially irrelevant auditory cues fail to orient visual attention. This finding suggested that crossmodal interaction did indeed have many asymmetries as earlier studies had suggested.[16] In 1997, Spence and Driver found "exactly the opposite asymmetry under different experimental conditions and with a different task" (Spence & Driver, 1997). The asymmetry was termed the "missing link" in crossmodal attention. Ward, McDonald, and Lin (2000) conducted one complex experiment to examine crossmodal asymmetry. Thirty-eight subjects participated in the study with twenty assigned to the visual task condition and eighteen assigned to the auditory task condition. The experiment was conducted in a dark chamber with three horizontally aligned speakers positioned so that the middle speaker was directly in front of the subject. Two peripheral speakers were placed to the left and right of the center speaker at equal lengths. Five light-emitting diodes were placed on each on the speakers. Green light-emitting diodes were placed at the center, left, and right, while red light-emitting diodes were placed above and below the center of each speaker. Auditory cues were comprised of two broadband noise bursts separated by a ten–msec. interval. Subjects were instructed to keep their eyes at fixation point and that the cues were not predictive of target location. After a fixation point appeared, either an auditory, visual, or both auditory and visual cue appeared from one of three locations replicating the sixteen possible cue defined conditions that Ward (1994) used in a previous experiment. The stimulus onset asynchrony times were 100, 200, 550, or 1050 msec. The task was to respond quickly by

[16] In particular, the Buchtel and Butter (1988) study that is cited herein. This study was illustrative of the time of early studies that found such inconsistencies. For an additional example, see Levick et.al 1993.

pressing a button with the dominant hand when the target appeared left or right of fixation (go trials) but to withhold response when the target appeared at fixation point (no-go trials). The subjects endured three sessions including 1,850 trials. The authors conducted a 6 (condition) x 4 (SOA) x 2 (validity) MANOVA for repeated measure design.

The complicated design yielded four important results. First, the authors replicated the asymmetry that Ward (1994) initially found. Second, "the appearance of a visual cue did not facilitate responses to the visual target on valid-cue trials at the 100 msec SOA in any condition involving a peripheral visual cue" (Ward, McDonald, & Lin, 2000, p. 1262). Third, the visual cue reduced response time to the auditory target on valid cue trials at short SOA's, but inhibition of return was not significant at longer SOA's. Last, conflicting cues had different effects on responses to visual and auditory targets. The authors noted that the appearance of a conflicting auditory cue had little or no influence on the IOR effects of the visual cue on responses to the visual target. These findings implied that the auditory cue did not influence the ability of the visual cue to generate visual IOR and were consistent with the proposal that "the auditory cue did not orient visual attention or generate visual IOR" (p. 1262). Ultimately, the authors concluded that strategic effects and a complex cue environment explain the conflicting results of Ward (1994) and Spence and Driver (1997). Hence, the missing link is an effect based on the task, environment, and strategy employed to maneuver the trials, not a physiologic discrepancy in crossmodal interaction and functioning.

However, McDonald, Teder-Salejarvi, Heraldez, and Hillyard (2001) conducted an electrophysiological experiment that suggested that the missing link was a physiological mechanism without regard to task and environmental issues. Thirteen subjects participated in a spatial cueing/target decision task similar to the Ward, McDonald, and Lin (2000) experiment. Subjects were monitored for electrophysiological signals from sixty tin electrodes. Horizontal electrooculographic (EOG) signals were recorded "bipolarly using electrodes at the left and right external canthi" and vertical EOG information was recorded "using an electrode below the left eye" (p. 144). Ward et al. (2000) found strong physiological evidence that a structural missing link does exist. "Orienting attention to a nonpredictive visual cue does facilitate responses to nearby auditory targets when the stimulus onset asynchrony was 100-300 ms." (p. 146). Ward et al. (2000) argued that previous failures to obtain this result was based task inadequacies and experimental design inaccuracies. The missing link was concrete evidence that a supra coordination mechanism exists to regulate intermodality attention.

Synesthetic Correspondence: Vision and Touch. Unimodal sensory research dominated the study of perception for over a century. Most researchers focused on visual perception and attention (Hochberg, 1978). Tactile perception and processing was the last of the senses to be studied unimodally and the last of the senses to be included in crossmodal study (Macaluso, Frith, & Driver, 2000). As a result, the volume of research on vision and touch far exceeded the amount of research that included tactile senses. Martino and Marks (2000) embarked on an investigation to replicate some of the basic findings for vision and hearing and to extrapolate the findings to vision and touch. The authors hypothesized that if the results were replicated, the crossmodal sensory interactions would be governed by a common mechanism. For the tactile stimulus, experimenters used sound generated by a computer and delivered to the participant's hand through a stylus.[17] For the visual stimulus, white and black squares were presented against a gray background. For each trial, subjects received both a visual and vibratory stimulus and subjects would randomly be told to attend to either the visual or the tactile stimulus and to respond as quickly as possible by pressing the correct key for black or white/high or low stimulus. Researchers performed a condition (baseline, orthogonal) x congruence (match, mismatch) analysis of variance. As expected, matched stimuli were identified 16 ms faster than mismatched stimuli. The authors also conducted a task (visual or tactile) x condition x congruence analysis of variance. The results indicated that subjects classified visual stimuli 144 ms faster on average than tactile (578 ms compared to 434 ms). One of the most dramatic conclusions was that "participants could not attend wholly to stimulation of one modality without intrusion from stimulation of another modality" (p. 750). The authors found inconsistencies in selective attention across modalities. The authors concluded that "the processes underlying crossmodal interactions between vision and touch are likely to be similar, although not identical, to the processes underlying interactions between vision and hearing (p. 753)". As such, this experiment suggested that a common mechanism does not coordinate crossmodal interactions, but that the mechanisms are linked in the process of coordination.

[17] Researchers were careful to eliminate any noise that the tactile frequency generated.

In another series of experiments reported by Driver and Spence (1999), they found that proprioception acted as a third modality influencing attentional interaction when tactile stimulus was combined with different locations in an experimental condition. In a creative experiment, Spence and Driver (1997) had subjects hold a vibrotactile device in each hand and to respond to visual stimulus presented in front of the subject either on the left or the right. In half of the trials the participant held their hand in normal position and in the other half subjects crossed their hands. The basic conclusion was that regardless of physical position of the hands, subjects updated their spatial mapping even when the hands were crossed. Driver and Spence (1999) concluded that proprioception negotiates and links the auditory and visual modalities. While further research is certainly warranted, researchers are beginning to evaluate and better understand the tactile sensory modality.

Expectancy. A common theme in attention research was the role of cueing and expectancy. Spence & Nicholls (2001) conducted an experiment to examine the role of expectancy using auditory, visual, and tactile targets. In this experiment, subjects sat at a table in a dark room with screen a directly in front; a green light emitting diode served as fixation point. Two circular loudspeakers were placed 41 degrees on each side of the fixation point. Participants placed their left index finger over a tactile stimulator located on top of the left loudspeaker and their right index finger over a tactile stimulator located on top of the right loudspeaker. Participants were unable to see their hands. The tactile target was the presentation of a circular rod underneath either the left or right index finger. Auditory targets were white noise at a 90-db level. Visual targets were presented on the screen in front of the participant. Participants responded with pedals below each foot. The two within-subjects factors were target modality (auditory, visual, or tactile) and block type. Twenty students participated in four blocks of twenty practice trials followed by sixteen test blocks of forty-eight trials. Participants were given the probabilities for each upcoming block of trials and were told to divide their attention equally in the divided attention block and to attend to the most likely mode in other trials. When the target was in the modality expected, response time was significantly faster in the expected modality. The authors noted "that the largest costs of expecting the wrong modality all involve touch (p. 332)." In response to the concern that stimulus-driven effects might be confounded with expectancy effects, the authors reduced the stimulus-driven effects by simply eliminating all ipsomodal trials.[18] The researchers concluded, that "significant costs of attending to the wrong modality were found in every case (p. 334)." Further analysis also indicated no significant difference in speed or accuracy between any of the modalities; participants did not seem to be superior in any one modality. Subjects had more trouble shifting away from the tactile modality compared to the other modalities. Finally, the authors concluded that response time benefits were most likely from priming from a previous trial in the same modality.

Potential Problems with Crossmodal Attention Research

As is the purpose of scrutiny by the scientific community, many researchers began to note methodological and construct problems with existing experimental

[18] The objection raised by Spence and Driver (1997) is discussed in the next section of this paper. Ipsimodal trials are simply those trials that were preceded by the same modality in the previous trial. Hence, they removed any trials that had the same modality expected back-to-back.

investigations and designs. The first objection concerned the role of priming in various experiments. Spencer and Driver (1997) suggested that many of the empiric investigations were contaminated with priming artifacts, and that subjects exhibited efficient practice and priming effects that diluted the conclusions of the experiment. Most of the experiments deployed simple response time tasks that measured attentional shifts. Mahrer and Miles (1999) suggested that subjects developed efficient criteria for within task performance based on target expectations. Some of the response time costs were due to shifting and moderating criteria as opposed to attention shifting. In particular, when exogenous cues were used and the experimental duration was substantial, cognitive structures created these criteria and the experimenter was measuring the time the subject takes to shift the cognitive or connectionist map rather than a purely attentional shift. Ultimately, Mahrer and Miles (1999) concluded that sensory memory, coupled with attention-biasing and cognitive strategies that limited encoding resources, was focused on the specific task at hand, and could easily explain the data from previous research (Mahrer & Miles, 1999).

A third potential problem is that the stimuli used in many experiments were encouraging subjects to shift modality without regard to cueing type. Yuejia and Jingham (1997) found that a deviant stimulus was modality-specific and standard stimuli was cross-modally determined and suggested that the type of stimulus can be a critical confound in many experiments. In a related manner, Dittmann-Balcar, Thienel, and Schall (1999) concluded that crossmodal processing and resource allocation was often a function of specific task requirements and stimulus demands. In a more general allegation, Spence and Driver (1997) suggested that most crossmodal studies contained exogenous and endogenous cueing confounds. The scientific community questioned the nature and role of the particular task and stimulus relative to the dependent variables under investigation. Given that the rigorous testing of crossmodal attention and multisensory coordination has been a recent occurrence, the relations between and within sensory modalities have not been isolated from the effects of task and stimulus in many studies.

A final reservation about current research was by far the most prevalent and posed an eminent threat to the veracity of many investigations. The dissent revolved around the scientific delineation of spatial cueing from modality cueing. In many investigations, researchers attempted to cue the subject by modality, but Quinlan and Hill (1999) presented clear data that suggested that spatial and modality cueing were confounded in most experimental designs. When one can isolate spatial orienting and modality orienting, clear significant differences on the dependent measure were evident. When the two types of orienting are confounded in an experiment, the results of the experiment were skewed and could not be interpreted without removing the confounding. Other authors expressed similar concerns that if perception did involve a parallel mechanism, then multiple modality interactions could exist simultaneously without respect to spatial location (Pylyshyn, & Storm, 1988; Schmitt, Postma, & De Haan, 2000). In which case, the experimenter could be intending to cue modality and actually cueing spatial location. Spence and Driver (1997) noted that any study in which auditory and visual cues were started from a different location are likely to be saddled with this problem.

Key Research Applications

While some researchers grappled with the technical details, others conducted experiments with intersensory modality manipulations with known problems and specific situations. Three fields that have benefited from crossmodality research are sensory compensation, autism, and comprehension skill. Research has been applied and studied to address particular real world problem, questions, and needs.

Sensory Compensation in Visual and Auditory-Impaired Subjects. Of clear interest in crossmodal attention research has been assisting or aiding those with sensory impairments. If crossmodal functions and attention are linked or governed by a supra mechanism, then one might assume that a healthy sensory system might compensate for the impairment in one mode with superior performance in another mode. Even though the research indicating such a proposition was slight, Dufour & Gerard (2000) concluded that auditory functions were superior in visually impaired subjects. In an historic work, Izuminyama (1957) reported that auditory perception was superior in blind children compared to normally sighted children.[19]

In an investigation addressing the notion of modal compensation, Roennberg (1995) defined perceptual compensation as "dependent on that/those psychological or neurological process(es) or mechanism(s) that, due to partial or complete loss of sensory input in one modality, stimulate(s) development or improvement of a perceptual function in another modality" (p. 251). Furthermore, the perceptual improvement must be

[19] This body of publication is rich with practitioner-oriented educational materials that proffered heightened auditory capabilities in visually impaired patients, but none of this theoretical discussion has been tested empirically. As such, much of the qualitative articles have not been included herein.

significantly distinct from a matched control group. As such, the interesting question was not whether impairment in one modality leads to practiced enhancement in another, but rather if a neurological/cognitive mechanism increased the capacity or sensitivity of another modality to compensate. In studies conducted in 1934, Hayes concluded that sound localization was not superior in blind subjects (Hayes, 1934 as cited in Roennberg, 1995 p. 253). In fact, Hayes worked with Helen Keller to determine if her tactile modality was superior given her visual and auditory impairments. Again Hayes (1934) concluded that he could not isolate a physiologic superiority of tactile response in the blind and deaf. Sakurabayashi and Sato (1956) concluded that blind students were not superior compared to normally sighted students with respect to pitch, loudness, rhythm, duration, timber, and tonal memory or sensitivity. Bross and Sauerwein (1980) conducted an experiment to compare the visual resolving power of deaf and hearing subjects. They concluded that deaf subjects displayed no significant difference in their visual capabilities as compared to the hearing subjects. Bross and Borenstein (1982) further weakened the compensation postulate by testing the auditory sensitivity of blind subjects compared to sighted subjects. Bross and Borenstein (1982) found no statistically significant difference in auditory sensitivity between the blind and sighted subjects.

In a related investigation, Bross, Harper, and Sicz (1980) found that compensation occurred within a modality. The authors also found that visual acuity decreased and increased after twenty-four hours of auditory deprivation. As early as 1980, Bross and his colleagues suggested that a common governing mechanism was responsible for multimodal coordination. Even though research indicated that compensation does not occur in one modality when another is impaired, the field of visual impairment offered support for the linked and supra models of crossmodal coordination.

The consensus among scholars was that perceptual learning occurs to enhance one modality when another is impaired (Conrod, Bross, & White, 1986). However, the preponderance of evidence suggested that physiological compensation does not occur and that the whole notion is a myth as opposed to reality (Roennberg, 1995). Perhaps any compensatory results were due to cognitive compensation, not physiological.

Autism: A Crossmodal Deficit. Another interesting application of crossmodal attention has been the study of autism. Researchers hypothesized that autistic individuals have a problem with spatial attention (Wainwright-Sharp & Bryson, 1993). Specific investigations confirmed that autistic individuals have general attention shifting deficiencies (Strandberg, Marsh, Warren, & Asarnow, 1993). Many researchers described autism as a severe form of focused attention and an inability to disengage attention (Wainwright-Sharp & Bryson, 1993). Wainwright-Sharp and Bryson (1993) confirmed this inability using a valid/invalid cueing task adapted from the crossmodal research. In this study, autistic patient response time was compared to normal subject response time on the visual cue task with a tactile response mode. Autistic individuals had consistently slower response times. The authors concluded that autistic subject demonstrated significant impairment in attentional and information processing.

Courchesne, Townsend, Akshoomoff, and Saitoh (1994) used another visual and auditory task to discern motor or attentional impairment in autistic individuals. They concluded that autistics had a problem coordinating rapid attention shifts between modalities. Applied research documented that crossmodal coordination was impaired in autistic, which contributed to problems with attentional functioning. In 1970, Bryson demonstrated the crossmodal problem in autistics using visual, verbal, and tactile tasks with autistic children. Bryson (1970) concluded that the autistic children were competent within modality but had trouble making crossmodal associations and integrations. As such the research in crossmodal attention has assisted physicians and caretakers to study, understand, and entertain possible treatment plans for autistic individuals.

Comprehension Skill and Modality. Comprehension skill measurement is another application of crossmodal research. Gernsbacher, et al. (1990) suggested that "general comprehension skill transcends modality" (p. 430). Gernsbacher and her colleagues created a multimedia comprehension battery (MMCB) that tests pictorial, textual, and auditory modes against comprehension. The MMCB consisted of six stories with two written, two auditory, and two visual presentations. Gernsbacher et al. (1990, 1991) concluded that subjects skilled at comprehending in one modality were equally skilled at comprehending in another modality. Figure 5 depicts the results reported and Table 11, 12, and 13illustrate the validation of the multiple choice test approach, as opposed to the free recall approach. With respect to differences in modality ability related to comprehension, Gernbacher contended that a suppression mechanism predicted comprehension skill, not a specific modality preference or a specific modality aptitude (Gernsbacher, 1993).

Li, Jordanova, and Lindenberger (1998) found that tactile, visual and auditory modality performance was highly correlated with intellectual ability. The research suggested that modality-specific task performance was associated with measures of fluid intelligence. However, Li et al. (1998) did not consider a more ubiquitous common construct that could have accounted for the association. Task performance in one modality compared to another modality could be associated by a more primitive cognitive construct such as inhibition or working memory. Further research and investigation is needed to determine whether modality performance is predictive of general fluid intelligence and academic performance.

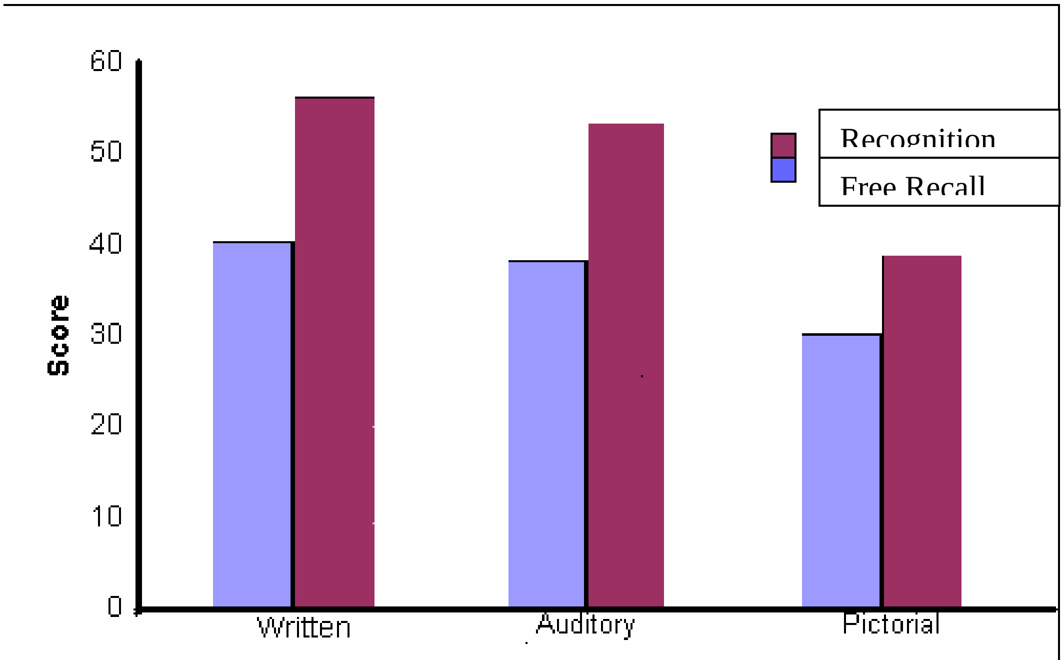

Figure 5. MMCB modality scores by assessment type.

Table 11. Means and standard deviations of participant scores on the MMCB by test type

Test Type	Story Type Written (Text)		Auditory		Pictorial	
	M	SD	M	SD	M	SD
Free Recall (n=69)	40.04	9.51	38.17	12.72	20.03	8.15
Recognition (n=85)	56.16	8.64	53.22	9.45	39.25	5.59

Table 12. Post Hoc Pairwise Comparisons: Assessment type at each modality
Tukey Critical F=8.12 (6 means, 152 df)

	Free Recall		Recognition	
	Auditory	Pictorial	Auditory	Pictorial
Written (Text)	.98	13.25*	2.15	13.75*
Auditory		9.97*		11.36*

*Significant at the .001 level

Table 13. Post Hoc Pairwise Comparisons: Modality at each assessment type
Tukey Critical F=8.12 (6 means, 152 df)

	Written (Text)	Auditory	Pictorial
Recognition compared to Free Recall	10.89*	8.18	15.38*

*Significant at the .001 level

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APPENDIX C

EXPANDED LITERATURE REVIEW AND HISTORICAL FOUNDATIONS: COGNITIVE THEORY OF MULTIMEDIA LEARNING

Overview of Theory

Mayer (2001) defined multimedia learning as any electronic presentation involving words and pictures that is intended to foster learning; based on how the mind works. He outlined three prominent approaches to the design of multimedia: the delivery media approach, the presentation mode approach, and the sensory modality view. The delivery media approach focused on the technology and centers design around the technology, not the learner. Presentation mode spotlighted the quantity of material displayed to the learner in two or more modes. The sensory modality view revolved around the congruence of multimedia modality and cognitive structure. Mayer's (2001) Cognitive Theory of Multimedia was a mixture of the presentation and sensory modality approach. In reviewing computerized learning materials, Mayer (2001, 2002) concluded that the majority were centered on technology, not learning. He suggested that this technology-centered approach was driven by the delivery of information, not in promoting learning. He proposed a learner-centered approach that used our knowledge of human cognition to create materials that fostered learning. The goal of the information delivery method was to promote information acquisition, which Mayer argued is different from knowledge construction (Mayer 2001, 2002).

Mayer (2001) envisioned the following components of knowledge construction

- Process structures – cause and effect chains; how some system works
- Comparison structures – compare two or more structures along several dimensions
- Generalization structures – main ideas and subordinate ones (branching trees)
- Enumeration structures– lists and consist of a collection of items
- Classification structures – hierarchical and contain sets and subsets

Mayer used these components to design retention and transfer tests associated with his multimedia learning materials. Inherent in knowledge construction were five steps to learning: selecting relevant words, selecting relevant images, organizing selected words, organizing selected images, and creating a coherent mental representation. Mayer (2001) argued that the ultimate goal of any multimedia learning lesson should be the integration of information into a coherent mental representation. Using this paradigm, Mayer (2001) articulated practical guidelines for multimedia design.

Description of Mayer's Experimental Materials

For his experiments, Mayer designed a set of process-based, brief texts such as; how lightning storms develop, how brakes function, and how pumps work. Mayer created a multitude of multimedia combinations for all three texts and administered the texts and transfer tests experimentally: lightning (Mayer, 1998; Mayer, Bove, & Bryman, 1996; Mayer, Heiser, & Lonn, 2001; Mayer & Moreno, 2002; Moreno & Mayer, 1999); brakes (Mayer, 1998; Mayer & Anderson, 1992; Mayer & Gallini, 1990; Mayer & Moreno, 1998) and pumps (Mayer & Anderson, 1992). As he reported in 2001, Mayer developed multimedia conditions using Director for the Apple Macintosh (Mac), an animation authoring tool that is now antiquated for the Mac. In order to test the efficacy of multimedia combinations, Mayer and colleagues created three primary conditions: animation and written text; animation and auditory (narration); and animation, written text, and narration. The participants watched the pictorial depiction of the lesson as they listened to the descriptive narration. Hence, in the animation and written text condition, participants watched the same animation and read the descriptive text. In the third condition, participants were exposed to all three modalities: they listened to the narration, read the written transcription of the narration, and watched the associated animation. Note that the animation was consistent across all conditions and the written and spoken texts are identical. The entire text is reported below. Upon completion of the multimedia lesson, participants completed either a retention test or a transfer test. The retention test was an elemental measure of recall, asking the participant to recall the steps in the lesson. The transfer test focused on measuring the learner's deeper understanding of the materials, measuring the ability to extrapolate and apply the material. Mayer (2001) noted that as an educator, he was primarily interested in the transfer test performance.

Lightning Module Text

The following script was used in the lightning multimedia learning lesson (Mayer, 2001):

> "Cool moist air moves over a warmer surface and becomes heated. Warmed moist air near the earth's surface rises rapidly. As the air in the 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 ice crystals. Eventually, the water droplets and ice crystals become too large to be suspended by the updrafts. As raindrops and ice crystals fall through the cloud, they draft some of the air in the cloud downward, producing downdrafts. When the downdrafts strike the ground, they spread out in all directions, producing gusts of cool wind people feel just before the start of the rain. Within the cloud, the rising and falling air currents cause electrical charges to build. The charge results for 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. The upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of "lightning" (pp. 27-28)".

Portion of the Lightning Module Text Personalized

The following excerpt script was used to measure the impact of personalizing the text in the lightning multimedia learning lesson (Mayer, 2002):

"Let me tell you what happens when lightning forms. Suppose you are standing outside, feeling the warm rays of sun heating up the earth's surface around you. Cool moist air moves over a warmer surface and becomes heated. The warmed moist air near the earth's surface rises rapidly. As the air in this upward draft cools, water vapor condenses into water droplets and forms a cloud. Congratulations! You have just witnesses the birth of your own cloud."

As you watch, you tilt your head skyward. Your cloud's top extends above the freezing level, so the upper portion of your cloud is composed of tiny ice crystals. Brrr! I'm feeling cold just thinking it! Eventually, the water droplets and ice crystals become too large to be suspended by updrafts. As raindrops and ice crystals fall through your cloud, they drag some of the air in your cloud downward, producing downdrafts. When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind you feel just before the start of the rain. If you could look inside your cloud, you could see a neat pattern: Within the cloud, the rising and falling air currents cause electrical charges to build. The negatively charged particles fall to the bottom of the cloud and most of the positively charged particles rise to the top" (p. 130).

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APPENDIX D

EXPANDED LITERATURE REVIEW AND

HISTORICAL FOUNDATIONS: ROLE OF

INDIVIDUAL DIFFERENCES

Working Memory Capacity

The quest for isolation of the cognitive primitive has long been a theme for many experimental psychologists. One group argued that processing speed is the primitive that predicts cognitive task performance and can be delineated by age differences (Salthouse, 1996; Salthouse & Babcock, 1991). Another group contended that a primary inhibitory mechanism, that allows the suppression of irrelevant stimulus and information, is the cognitive primitive (Hartman & Hasher, 1991; Hasher, Stoltzfus, Zacks, & Rypma, 1991; Hasher & Zacks, 1988; Kane, Hasher, Stoltzfus, Zacks, 1994). A final research group, inspired by Baddeley and Hitch (1974), differentiated working memory capacity from short term memory capacity, as espoused by Miller (1956) and his "magical" number seven capacity estimation and conception for short-term memory. This group of researchers contended that working memory capacity is the cognitive primitive (Cantor & Engle, 1993; Carlson, Wenger, & Sullivan, 1993; Conway & Engle, 1994; Cowan, 1988; Jurden, 1995; Kimberg & Farah, 1993, Miyake, Just, & Carpenter, 1994; Nunez & Rojas, 1993; Roberts, Hager & Heron, 1994; Towse & Hitch, 1995; and Van der Linden, Bredart, & Beerten, 1994). Baddeley and Hitch (1974) proposed a dramatically different conception of memory compared to traditional unitary systems that encode, maintain, and retrieve (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). Baddeley and Hitch

(1974) proffered a continuous model of working memory with a central executive component managing two primary slave systems: phonological loop (verbal information processing) and the visiospatial scratchpad (visual/spatial information processing). Although research is proliferating, the specific details of central executive functioning and storage are still under investigation (Kintsch, Patel, & Ericsson, 1999).

Baddeley (1996) delineated four approaches to studying the central executive: dual task performance assessment; random number generation; selective attention manipulation; and long-term memory activation measurement. Regardless of research approach, the debate continues regarding storage and processing aspects of the central executive component of working memory. Baddeley (1996) maintained his position that the central executive includes both processing and storage features. Norman and Shallice (1986) conceived a supervisory attentional system, largely responsible for processing and control, while Dempster (1981) found that traditional notions of capacity did not predict memory span. In addition to research on the central executive, numerous investigations have studied the phonological loop (such as Baddeley & Andrade, 1994; Jones & Macken, 1995; LeCompte, 1994; Longoni, Richardson, & Aiello, 1993; Saito, 1994) and the visiospatial sketchpad (such as Hitch, Brandimonte, & Walker, 1995; Salway & Logie, 1995; Smyth & Scholey, 1994; Toms, Morris, & Foley, 1994).

An individual difference can influence the relationship between multimedia condition and test performance in two fundamental manners: as a mediator or as a moderator. Baron and Kenny (1986) outlined the specific criteria for determining whether a variable mediates the relationship between two other variables. The independent variable must be associated with the mediator variable and the mediator variable must be associated with the dependent variable. The independent variable must be associated with the dependent variable, but the relationship should disappear when controlling for the mediator variable. In cases in which the relationship between the independent and dependent variable is reduced but not altogether unassociated, then the mediator variable can be described as a partial mediator (Baron & Kenny, 1986). In terms of moderating variables, Anguinis and Pierce (1999) defined moderating variables in terms of a statistical interaction, where one or more variables predict an outcome for certain levels of another variable. For example, the predictive relationship between the multimedia principles and performance on retention and transfer tests may hold for certain conditions of a third variable, but not for all conditions. Typically the moderated variable has been dichotomized into low and high groups, but finer categories can be used to describe group membership as well.

Another way to distinguish mediating and moderating variables is that, "moderator variables specify when certain effects will hold; mediators speak to how or why such effects occur" (Baron & Kenny, 1986, p.1176). In terms of the discussion of individual differences and their impact on the relationship between multimedia condition and transfer test score, cognitive individual differences are temporally prior; a measured variable that fundamentally impacts, either completely or partially, the relationship. In hierarchical regression analyses, temporally prior variables are entered first in order to extract the variance known to be associated with the dependent variable. Once that "nuisance" variance is removed, one can explore the main effects and interactions in the analysis (Tabachnick & Fidell, 2001).[20] Mayer's work has been completely absent statistical examination of the interaction between several key cognitive variables and the modality and redundancy effect on transfer test performance. Rather, Mayer and colleagues focused on media manipulations, without exploring the reason that certain manipulations have an effect. In essence, they focused almost exclusively on the symptom, without consideration for temporally prior cognitive individual difference causes. In order to evaluate the superiority of animation and narration that Mayer espouses, the predictive validity and possible interaction of elemental individual differences with multimedia condition must be considered in order to scientifically evaluate the veracity of Mayer's modality and redundancy principles.

Multimedia Comprehension Skill

The Multi-Media Comprehension Battery (MMCB) developed by Gernsbacher and Varner (1988) has been used to measure multimedia comprehension skill in a large number of experimental manipulations. The MMCB tests comprehension skill across textual, auditory, and pictorial modalities. The MMCB is comprised of two written stories, two auditory stories, and two pictorial stories. The original materials were written in a DOS-based program intended for individual or small group administration. Gernsbacher, Varner, and Faust (1990) found that a general multimedia comprehension skill transcended any performance in a specific modality, indicating that subject modality preference must not impact overall performance. Gernsbacher et al. (1990) found that the correlation between written and auditory story comprehension was .92; the correlation

[20] Nuisance to the degree that the experimenter is not as interested in the variance associated with known a priori variables, but on the impact of remaining variables on the remaining variance.

between written and picture story comprehension was .82; and the correlation between auditory and picture story comprehension was .72. Hence the comprehension scores were collapsed into one general comprehension score that was argued to transcend modality. Gernsbacher et al. (1990) also found that each component of the comprehension skill test correlated with the verbal portion of the Scholastic Aptitude Test (SAT) (written, $r = .64$; auditory, $r = .57$; and pictorial, $r = .45$.) Maki and Maki (2002) found that the written, auditory, and pictorial comprehension scores were highly intercorrelated, with Pearson correlation coefficients ranging from .46 to .60. After combining the three components into a general comprehension score, Maki and Maki (2002) found that in a hierarchical regression analysis, after student background, course format, and instructor variables had been entered into the equation, comprehension skill contributed significantly to the prediction of content performance and examination performance.

A previous study by Stalcup and Maki (2002) replicated the overall pattern shown by Gernsbacher et al. (1990) as illustrated in Figure 1. The MMCB means and standard deviations by test type are reported in Table 2. A 2 (assessment type) X 3 (modality) ANOVA revealed a main effect of modality $F(2, 152)=202.12$, $MSE=42.02$, $p<.001$; a main effect of assessment type $F(1,152)=130.57$, $MSE=166.55$, $p<.001$; and an interaction between assessment type and modality, $F(2, 152)=8.96$, $MSE=42.02$, $p<.001$. Table 3 indicates that, in spite of the interaction between assessment type and modality, pairwise post hoc comparisons using a Tukey-corrected critical F revealed that written and auditory modalities in both assessment conditions are not significantly different, but written/pictorial and auditory/pictorial are statistically different for each assessment type. Data collected established that recognition and recall were statistically significant for each modality type; recognition scores were consistently higher for each modality. An evaluation of the means in Table 1 indicates that the advantage of recognition assessment type was slightly less for the pictorial condition. Hence, students' comprehension scores were higher on the written (text) and auditory tests compared to the pictorial, regardless of assessment type. The recognition assessment type yielded higher scores overall compared to the free recall assessment type, with a slightly smaller advantage in the pictorial condition.

In terms of the relationship among the MMCB story scores, the correlation between written/textual and auditory was .77; the correlation between written/textual and pictorial was .61; and the correlation between auditory and pictorial was .68 (all correlations were significant at the .001 level). A simultaneous regression analysis revealed that MMCB comprehension scores accounted for 10.9% of the variance in verbal SAT scores, which represented a significant portion of the variance $F(3,149)=6.09$, $MSE=.57$, $p<.001$.

To more precisely examine the statistical relationship among the three comprehension scores, a maximum likelihood exploratory factor analysis was conducted and revealed one common factor, replicating Gernsbacher et al. (1990). The general comprehension factor yielded an eigenvalue of 2.373, accounting for 69.415% of the common variance among textual/written, auditory, and pictorial comprehension scores. The next eigenvalue for two factors was .40 followed by .22 for three factors.

Eigenvalues represent variance in a set of variables accounted for by one component or factor. Tabachnick and Fidell (2001) explained that all eigenvalues greater than one should be evaluated as indicators of a factor or component. While determining the number of factors in a model is far more complicated, eigenvalues and scree plots are good initial indicators.[21]

Fluid Intelligence

In 1904, Charles Spearman proffered a conception of general intelligence that continues to be a theoretical anchor in intelligence theory and research. Spearman (1904) equated general intelligence "g" to an omnibus mental energy, suggesting that all individual aspects of intelligence are subsets of a broad, general ability. Congruent with this approach, Spearman and Jones (1950) and Thurstone (1938) contended that "g" was a higher order construct comprised of second order cognitive abilities. Cattell (1943) distinguished between the notions of fluid intelligence and crystallized intelligence. While Cattell (1963) found that fluid and crystallized intelligence were highly correlated ($r = .70$), he argued that fluid intelligence represented the innate ability to problem solve and process patterns, while crystallized intelligence was the ability to retrieve and use stored material obtained by experience. Fluid intelligence is largely independent of prior knowledge and requires complex cognitive analyses (Horn, 1972). Horn and Cattell (1967) identified and isolated differences between fluid and crystallized intelligence: fluid intelligence declined with age, while crystallized increased with time; the fluid intelligence distribution had a standard deviation of 16 and crystallized intelligence a

[21] A Scree plot is the eigenvalues plotted against the number of factors. In order to determine a starting place for iteration analysis, one can inspect the plot for clear changes in the linear slopes.

standard deviation of 24; and fluid intelligence was impacted with any cortex damaged, while crystallized intelligence was only impacted by damage to specific areas of brain. Cattell (1982) further found that fluid intelligence was 80% heritable, while crystallized was 40% heritable.

As scientific evaluation continued, factor analytic studies yielded three prominent approaches to describing intelligence and its components. Eysenck (1967, 1979, 1988) developed a theory of intelligence that included three fundamental types of intelligence: elementary information processing (intelligence A, fluid intelligence was a component); acquired problem-solving skills (intelligence B, encompassed crystallized intelligence); and an artifact of averaging unlike abilities (intelligence C, included the notion of IQ). Eysenck (1988) argued that elementary information processing is genetically determined and can be measured with physiological tests, while the artifact of averaging unlike abilities was best measured psychometrically with cognitive skill tests. Hence, Eysenck (1988) maintained that fluid intelligence was entirely heritable, and findings to the contrary had confounded intelligence A and C.

In 1971 (revised edition in 1987), Cattell statistically demonstrated a triadic theory of intelligence. Cattell (1971) delineated intelligence into three hierarchical levels: broad factors, provincial factors, and agency factors. He argued that both fluid and crystallized intelligence were broad factors, along with short term memory and retrieval and long term memory and retrieval. He found factorial invariance among the broad factors and among the three levels of intelligence. Hence, the correlations reported among broad factors were an artifact of measuring broad factors with agency level or provincial level measurement tests. The agency level included primary abilities, such as numerical, verbal, spatial, spelling, word fluency, and inductive reasoning; and the provincial factors represented visual, auditory, and kinesthetic processing speed.

After an extensive and exhaustive meta-analytic factor analysis, Carroll (1993) published a "magnum opus" illustrating a three stratum theory of intelligence. Carroll (1993) isolated three levels of factors, arguing that all were both phenotypic (oblique) and genotypic (orthogonal). Congruent with Spearman's (1904) notion of "g", the third omnibus stratum was general intelligence and the second stratum delineated specific cognitive categories, which included: fluid; crystallized; general memory and learning; broad visual perception; auditory; cognitive speediness; retrieval ability; and processing speed. The third stratum was a collection of basic abilities, divided into level factors (primary ability) and speed factors. For example, the third stratum associated with fluid intelligence included level factors of sequential reasoning, induction, quantitative aptitude, and speed factors associated with reasoning. The third stratum associated with crystallized intelligence included level factors of language development, comprehension skill, lexical skill, reading, spelling, communicating and speed factors of reading, oral, and writing speed.

Note that in each of the three approaches, fluid intelligence was a major component of intelligence and consistently associated with elemental cognitive ability. While the factor-analytic psychometricians debated the theoretical and statistical structure of intelligence and cognitive abilities, other scholars diverted from the unimodal approach with a more eclectic multimodal approach to intelligence. Three prominent approaches suggested that the unimodal approach was theoretically limited and largely an artifact of statistical manipulation (Thurstone, 1936a, 1936b). Thurstone (1924, 1947) derived a theory of primary mental abilities: verbal comprehension, word fluency, number facility, spatial visualization, associative memory, perceptual speed, and reasoning. After administering a battery of cognitive skill tests, Thurstone and Thurstone (1941) reported seven constructs using factor analytic techniques and argued that the seven constructs were consistent with Thurstone's (1924) initial theoretical suppositions of seven primary abilities.

Representing a second dissention to the unimodal approach, Sternberg (1984, 1996) argued that intelligence must be examined in the context of three subcomponents: componential, experiential, and contextual. Componential issues included structures and mechanisms that underlie intelligent behavior. Experiential components referred to analyzing behavior in terms of task novelty or familiarity. Contextual parameters defined sociocultural and environmental influences on behavior. In terms of intelligence, Sternberg (1984) posited three components: analytic, creative, and practical. Sternberg and Wagner (1989) argued that only analytic intelligence could be captured and measured by traditional intelligence tests, which yielded an impoverished description of intelligence. A third dissenter, Gardner (1983) theorized seven primary forms of intelligence: linguistic, musical, logical-mathematical, spatial, bodily-kinesthetic, intrapersonal, and interpersonal. The multimodal approach to intelligence is still in its infancy and absent mature critical empirical investigation and testing.

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APPENDIX E
EXPANDED DETAILS OF METHOD

Multimedia Comprehension Battery (MMCB) Recognition Test Development

MMCB: Recognition Questions and Associated Scoring from “Hiram’s Red Shirt” (pictorial story):

1. How did Hiram fix the problem of his shirt being too short?
    - a. Took fabric from his pants (2 on recall)
    - a. Sewed longer pieces on it (0 on recall)
    - b. Stitched on a patch from sleeves (1 on recall)
    - c. Took fabric from the bottom of his pants (correct; 3 on recall)
    - d. Patched on some material from another red shirt (1 on recall)
2. Who disliked Hiram’s singing?
    - a. Sun (2 on recall)
    - b. Neighbor and the moon (1 on recall)
    - c. Moon (correct; 3 on recall)
    - d. Dog (0 on recall)
    - e. Dog and sun (1 on recall)
3. What did Hiram eat at the picnic?
    - a. Chicken leg and corn (correct; 3 on recall)
    - b. Chicken leg (2 on recall)
    - c. Corn (1 on recall)
    - d. Meat (1 on recall)
    - e. Hot dog (1 on recall)
4. How did Hiram fix his pants after they were too short?
    - a. Hemmed on a table cloth piece (0 on recall)
    - b. Added red material (2 on recall)
    - c. Patched on underwear to the bottom of the pants (1 on recall)
    - d. Sewed on the sleeves of his shirt (0 on recall)
    - e. Cut off material from his red shirt and added it to his pants (correct; 3 on recall, authors reworded slightly)
5. What did Hiram do before he went to the store?
    - a. Mended his nightshirt (1 on recall)
    - b. Fixed all his clothes back the way they belonged and got his piggy bank (correct; 3 on recall)
    - c. Repaired his pants to the way they were before (1 on recall)
    - d. Patched his pajamas the way they were before and took his money (2 on recall)
    - e. Got his piggy bank (1 on recall)

6. Why did the store attendant get frustrated with Hiram?

a. Hiram looked through several shirts (2 on recall)
b. Hiram did not know what to buy (0 on recall)
c. Hiram could not find a red shirt like he had (correct; 3 on recall)
d. Hiram took too long (1 on recall)
e. Hiram did not want fancy clothes (1 on recall)

7. Did Hiram take his coffee black or with sugar?
    a. Black (0 on recall)
    b. With cream (0 on recall)
    c. Hiram did not drink coffee (0 on recall)
    d. With Sweet-n-Low (0 on recall)
    e. With sugar (correct; 3 on recall)
8. What did Hiram use to repair the elbows of his shirt?
    a. Cuff links (2 on recall)
    b. Bottom of a red shirt (0 on recall)
    c. Parts of his shirt (1 on recall)
    d. His shirt cuffs (correct; 3 on recall)
    e. Jeans (0 on recall)
9. Why was cutting off his nightshirt not a very good idea?
    a. His skin was irritated by the wool blanket (correct; 3 on recall)
    b. He couldn't sleep (0 on recall)
    c. His nightshirt was too short (1 on recall)
    d. He got hurt (2 on recall)
    e. He got cold (0 on recall)
10. Where did Hiram keep his money?
    a. Jar (0 on recall)
    b. Piggy Bank (correct; 3 on recall)
    c. Under the bed (added, not on recall)
    d. With his red shirt (added, not on recall)
    e. Bank (1 on recall)
11. What was Hiram doing when his sleeves got in the way?
    a. Cooking pancakes (1 on recall)
    b. Slopping animals (2 on recall)
    c. Feeding the pigs (correct; 3 on recall)
    d. Brushing the horse (0 on recall)
    e. Doing housework (0 on recall)
12. Why was cutting of his pants not a very good idea?
    a. He fell in blackberries (2 on recall)
    b. He looked funny (0 on recall)
    c. His legs got hurt (1 on recall)
    d. He was attacked by prickly plants (correct; 3 on recall)
    e. He ruined his pants (0 on recall)

Recognition Questions and Associated Scoring from "Old MacDonald Had an Apartment"

1. What season was it when the story ended?
    a. Harvest (0 on recall)
    b. Winter (correct; 3 on recall)
    c. Fall (1 on recall)
    d. Spring (0 on recall)
    e. Summer (0 on recall)
2. What was Old MacDonald's original job?
    a. Repairman (1 on recall)
    b. Lawyer (0 on recall)
    c. Landlord (2 on recall)
    d. Superintendent (correct, 3 on recall)
    e. Fix-it man an plumber (1 on recall)
3. Which three vegetables did Old MacDonald raise?
    a. Lettuce, carrots, and apples (2 on recall)
    b. He only raised lettuce (1 on recall)
    c. Lettuce, corn, and carrots (correct, 3 on recall)
    d. He only raised corn (1 on recall)
    e. He only raised fruits and melons (0 on recall)
4. Who came to see Old MacDonald that smoked a cigar?
    a. Owner (correct; 3 on recall)
    b. Building inspector (0 on recall)
    c. Manager (0 on recall)
    d. His boss (2 on recall)
    e. Building superintendent (0 on recall)
5. What first sparked Old MacDonald's interest in gardening?
    a. Sick plant (2 on recall)
    b. Wife (0 on recall)
    c. House plant (1 on recall)
    d. Tomatoes in kitchen (1 on recall)
    e. Wife's tomato plant (correct; 3 on recall)
6. How did the first couple that left feel about leaving their apartment?
    a. Happy (0 on recall)
    b. Not thrilled (1 on recall)
    c. Heartbroken (correct; 3 on recall)
    d. Mad (0 on recall)
    e. Not too happy (1 on recall)

7. Why did Old MacDonald chop down the bushes at the beginning of the story?
    a. Get more light in the kitchen (2 on recall)
    b. They needed trimming (0 on recall)
    c. So he could plant vegetables (1 on recall)
    d. So light would allow the tomato plant to grow (correct; 3 on recall)

e. To make room for the garden (1 on recall)

8. What kind of pet did the couple who moved out last own?
    a. Chicken (0 on recall)
    b. Parrot (correct; 3 on recall)
    c. Dog (0 on recall)
    d. Cow (0 on recall)
    e. Cat (0 on recall)
9. How did Old MacDonald feel about the last tenants moving out?
    a. Fine (2 on recall)
    b. Embarrassed (0 on recall)
    c. Excited (correct; 3 on recall)
    d. Neutral (1 on recall)
    e. Mad (0 on recall)
10. Besides cows what other farm animals did the MacDonald's begin to raise?
    a. Chickens and dogs (correct; 3 on recall)
    b. Sheep (0 on recall)
    c. Dogs (1 on recall)
    d. Ducks (0 on recall)
    e. Chickens and pigs (Authors added; pigs on 0 point list on free recall)
11. Who owned a shotgun?
    a. Last couple that moved out (0 on recall)
    b. Another neighbor (2 on recall)
    c. People living below (1 on recall)
    d. Policeman (0 on recall)
    e. Upstairs neighbor (correct, 3 on recall)
12. Why did the owner change his mind about making the MacDonald's move out?
    a. He decided to set up a vegetable stand (2 on recall)
    b. They were making him money (correct, 3 on recall)
    c. He liked vegetables (0 on recall)
    d. Because they gave him some of the good produce (0 on recall)
    e. So he could turn the entire building into a vegetable store (2 on recall, with a little change in wording)