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The Effects Of Presentation Mode And Pace On Learning Immunology With Computer Simulation A Cognitive Evaluation Of A Multimedia Learning Resource

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THE EFFECTS OF PRESENTATION MODE AND PACE ON LEARNING IMMUNOLOGY WITH COMPUTER SIMULATION: A COGNITIVE EVALUATION OF A MULTIMEDIA LEARNING RESOURCE

by

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ABSTRACT

Multimedia learning tools have the potential to benefit instructors and learners as supplemental learning materials. However, when such tools are designed inappropriately, this can increase cognitive taxation and impede learning, rendering the tools ineffective. Guided by the theoretical underpinnings provided by cognitive load theory and the cognitive theory of multimedia learning, this study sought to empirically evaluate the effectiveness of a multimedia simulation tool aimed at teaching immunology to novices in an instructional setting. The instructional mode and pace of the tool were manipulated, the three levels of each variable yielding nine experimental groups. The effects of mode and pace on workload and learning scores were observed. The results of this study did not support the theory-driven hypotheses. No significant learning gains were found between the configuration groups, however overall significant learning gains were subsequently found when disregarding mode and pace configuration. Pace was found to influence workload such that fast pace presentations significantly increased workload ratings and a significant interaction of mode and pace was found for workload ratings. The findings suggest that the learning material was too high in intrinsic load and the working memory of the learners too highly taxed for the benefits of applying the design principles to be observed. Results also illustrate a potential exception to the conditions of the design principles when complex terminology is to be presented. Workload findings interpreted in the context of stress adaptation potentially indicate points at which learners at maximum capacity begin to exhibit performance decrements.

For my family, to whom I dedicate my life. You are my inspiration, my driving force. Your love, support, and guidance have made me who I am, my achievements are also yours. You all had faith and always believed that I already was what I one day wanted to be. Thank you Mom, Dad, and Rudy for supporting me in ways too numerous to detail here, not only in this work, but in all that I do. Thank you for having patience when I lost sight of the path and for always believing I would find my way back and succeed. Thank you Jessica and Steve for always supporting me without question, and Georgia and Hayley for the love and joy you bring to me. And I thank my wonderful Friend for showing me the finish line and dragging me across. I’m blessed to have you all, I don’t think I could have made it without any of you.

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CHAPTER 1: INTRODUCTION

Advances in technology have long ago transformed the traditional classroom into a multimedia experience. The average classroom of today will incorporate a variety of tools with which to present information to students, new forms of presentation develop quickly with computers being the most notable and versatile. The dawn of the internet allowed for instant information delivery and mass dissemination of information to users and presented an opportunity for teaching like never known before. With a wealth of knowledge now available at our fingertips, educators are faced with how to organize and present information so that it is absorbed appropriately and efficiently. As technology evolves and becomes readily accessible to educators and students alike, educators must learn to harness the tools that are at their disposal and developers must learn to create these tools to promote effective learning, that is by incorporating into design what is known about how people learn.

As technology continues to develop and becomes an increasing presence both within and outside the classroom, students today are growing up immersed in what could be termed a digital age. This notion has given rise to debates regarding how people are affected by digital immersion. Prensky (2001a) argues that digitally native students of today who grew up surrounded by and thus are well versed in the language of technology are no longer the kind of students a traditional educational system was designed to teach. In contrast, Prensky terms those who did not grow up digitally immersed but have transitioned later in life to the use of technology as digital immigrants. The difference between natives and immigrants is that immigrants retain what Prensky calls the “accent” of their technology lacking past while natives know only a digital language. Further, Prensky (2001b) proposes that as a result of technology being present all their lives, digital natives' brains are likely physically different from those who did not grow up in this digital age. This concept of digital nativity has the potential to influence what is known about how people learn which would in turn have implications for instructional design.

Prensky (2001a) identifies the struggle of digital immigrant teachers attempting to instruct digital natives who speak a different language as one of the largest issues facing the educational system today. Prensky also argues that immigrants are the ones that must cross the divide and adapt to the natives' way of learning. Black (2010) supports Prensky in his assertions and describes "gen Y" as students who are more expectant of the use of technology in their education, who expect higher grades yet are not prepared for the required work load because they are lacking in fundamental skills in mathematics, reading, and writing due to their dependence on technology, and who insist on accommodation to their specific needs and expectations. However, not all agree with the severity of the claims and consequences made regarding digital nativity and cite a lack of empirical evidence for the phenomenon. There is also a debate on whether there is an entire generation of skilled digital natives or perhaps only a partial one (Bennet, Maton, & Kervin, 2008).

Bennet et al. (2008) provide us with a critical review of supporting evidence on the subject of digital nativity. In their review of the research, Bennet et al. sought to find support for the two key claims of digital nativity: that there is an entire generation of digital natives in existence with a distinct learning style and that educational systems must change to accommodate these natives. Bennet et al. found some evidence that a certain proportion of students today are indeed more skillful with technology and depend on it for information gathering and communication. However, the authors caution that an all-encompassing claim of digital nativity can not be made because different cognitive abilities and learning preferences must be accounted for and there are still a number of students of who are not as interested in technology or do not have ready access to technology to develop the tech-savvy characteristic of the digital native. Further, Bennet et al. investigated the claim that digital natives think and therefore learn differently from non-natives and prefer a higher paced, multitasking based type of learning (such as that presented in a video game) and but did not find clear empirical support for this. Nor was definitive support found for recreational video games facilitating true learning. Finally, claims for a necessary and immediate sweeping change in instructional resources to accommodate the needs and demands of digital natives were largely unfounded. The research of Bennet et al. has served to place a cautionary view on how digital nativity is received and adjusted for and tempers the urgency for dramatic (and likely inappropriate) change.

Margaryan, Littlejohn, and Vojt (2011) cite a lack of empirical evidence supporting the notion of digital nativity in the literature and sought to empirically investigate the existence of digital nativity in a study of their own. The authors found that university students classed as digital natives did use technology more than digital immigrants, but this difference was shown quantitatively in how much technology was used not qualitatively in the type of technology used. Though digital natives used conventional forms of technology more, and this use might result in a greater ability than that of their instructors in the use of the technology, students and instructors both were largely unaware of how technological tools could be used as educational tools to support effective learning. Further, students were found to be influenced in their learning expectations by their instructor’s approach to teaching rather than by an internal change in learning pattern due to digital nativity. The authors contend that this challenges the notion found in digital nativity theory that asserts that digital natives are naturally sophisticated in their technology use and as such would exhibit or adapt to a different learning pattern. How students interact with technology is certainly more complex than digital nativity suggests and further research focus would be well placed on determining the true attributes of today’s students and matching them with effectively developed technological learning resources.

While the debate goes on about the specific changes in students of today and the potential differences and need discrepancies between older and younger generations of technology users, there is no doubt that the classroom is already changed from a traditional only setting and many at the very least combine some type of technology with traditional methods to deliver information. With this ever increasing inclusion of technology into education, it must be conceded that technology has instituted some sort of change both in and on learning and learners today. The role technology is given in a classroom and its corresponding sophistication level likely varies widely and depends on a number of conditions, not the least of which is the comfort level of the instructors or students using it. However, because technology is a resource that is more than likely to have staying power, developers and researchers must strive to design effective, user friendly tools that facilitate true learning for those who choose to use technology to meet their educational goals both inside and outside the classroom.

Implementing Multimedia in Education

Computer aided multimedia learning tools have the potential to benefit teachers and learners as supplemental materials to both traditional and non-traditional instruction. Multimedia learning is by definition presenting learning material through multiple media, most often via visual and auditory methods (Cook, Zheng, & Blaz, 2009). The very structure of a classroom continues to change as classes are offered face to face, via recordings, and distantly over the internet. Teachers and students need not meet together in the same room or attend live classes anymore. This growth of convenience has afforded an opportunity for many more people to gain an education, but it has also deepened some of the existing troubles for educators and students. Large classes and limited classroom time pose a problem because they limit the amount of material an instructor can teach in a session and reduces the possibility of interaction between students and teachers for clarifying material or other instructional needs. Web based instruction and distance learning are thought to have further widened that gulf between students and teachers (Mason, Helton, & Dziegielewski, 2010). Thus, the need for effective supplemental materials is becoming even more necessary as class sizes increase and classrooms, and thus students and teachers, become more remote and distance learning becomes more popular. Computer aided multimedia learning tools have the potential to help fill this gap and provide information and learning opportunities beyond the classroom and perhaps do so in a manner that engages the learner and promotes effective learning (Salas & Cannon-Bowers, 2001). Though many classrooms today still rely on traditional methods at least in part, computer aided instructional tools are drawing interest and approval from instructors because they can produce a reproducible and consistent means of educational material delivery and theoretically are adaptable to individual learning styles and needs (Lynch, Steele, Johnson Palensky, Lacy, & Duffy, 2001).

Further, in recent years much attention has been placed on using video games and simulations as cost effective methods of delivering learning and training experiences. Historically simulations have been successful as learning tools (Salas & Cannon-Bowers, 2001). Video games, while not necessarily thought to be effective educational tools in their recreational form, are thought to be engaging to users and people are viewed as being motivated to use them. Researchers wish to harness the motivational properties of games and blend them with the success of simulations as learning tools and use the outcome to develop effective learning tools that learners are excited about using and are motivated to use often (Vogel, Vogel, Cannon-Bowers, Bowers, Muse, & Wright, 2006).

It is important to develop supplemental learning tools that fit the human and target end goal learning outcomes effectively. This is to say it is essential to focus not only on developing the technology itself, but on developing effective user friendly tools that a multitude of people can use with ease whether they are “digital natives” or not. A clear distinction is made by Mayer (2009) between two approaches to developing multimedia tools for learning. A common approach, but typically ineffective with regard to improving education, is one centered on developing the technology itself without taking into account human cognition. Thus, a learner centered approach begins with considering how the human learns and adapts the tool accordingly. When designing tools for use in education, it is critical to take a user centered approach and draw upon what is known about how humans learn and incorporate that into the design. If a tool is not designed from a learner centered approach, is not properly designed for target outcomes, and quite plainly just doesn’t do what it is supposed to do, it will likely fail as an education tool. This is seemingly a tall order as researchers attempt to successfully translate identified learning outcomes into a tool that is appealing to a learner and easy for an instructor (or learner) to use and manipulate (Vogel et al., 2006). Key to the success of designing a successful multimedia tool for education is guiding the development by research based theory demonstrating how people learn, how material is best presented, and subsequently evaluating the tool for effectiveness. There are two primary theories available to guide multimedia design for learning, cognitive load theory and the cognitive theory of multimedia learning. These theories take into account what is known about the capabilities and limitations of the human learning process and use this information to provide design recommendations for multimedia learning tools. The utilization of theories such as these allows researchers to design tools that facilitate efficient learning and avoid inappropriate cognitive taxation of the learner that would otherwise negatively affect learning.

Rationale for Current Study

When instructional materials are designed inappropriately, the learning process becomes inefficient and ineffective, thus increasing cognitive taxation and impeding learning. Guided by the theoretical underpinnings provided by cognitive load theory and the cognitive theory of multimedia learning, the current research seeks to empirically evaluate the effectiveness of a computer based multimedia simulation tool aimed at teaching immunology in an instructional setting. The modality and redundancy design principles outlined by the cognitive theory of multimedia learning will be applied and tested to determine the most appropriate design for the presentation of the material to reduce cognitive load and promote effective learning.

CHAPTER 2: LITERATURE REVIEW

Critical to the successful development of any multimedia learning tool is an understanding of how people learn. This literature review will begin by reviewing a history of learning theory and will move into a discussion of the architecture of memory from a cognitive viewpoint of the learning process. This cognitive theory of learning lays the foundation for multimedia theory development. Following the review will begin a discussion of cognitive load theory and the cognitive theory of multimedia learning and how these theories have been developed and applied in research.

Learning and Memory

A Brief History of Learning Theory

A review of learning theory throughout history reveals four prominent and somewhat overlapping theories: behaviorism, cognitivism, constructivism, and social learning. Though the current research is principally based in cognitive learning theory, and as such much of the present literature review will address theory, issues, and research pertaining to cognitive learning and in particular multimedia learning, a brief and basic review of all these viewpoints is also warranted. It is important to note that although these four theories have historically predominated the field, they by no means represent a comprehensive listing of learning theories and additional theories continue to emerge and develop.

Behaviorism was initially posited by John Watson nearly a century ago and was further developed during a mid-century revival most notoriously by Edward Thorndike and B.F. Skinner. Behaviorism focuses on the behaviors of a learner and what is measured are behaviors that are outward and observable (Bush, 2006). According to behaviorists, a change in behavior is an indication of learning. Key to a behaviorist view of learning is how the behavior of a learner changes in response to stimuli provided by the environment and how reward, reinforcement, and punishment affects behavior, concepts central to classical and operant conditioning (Domjan, 1996; Reisberg, 2001). Basically stated, behaviors are conditioned responses to stimuli. With the environment providing the stimuli, including rewards, reinforcements, and punishments, to a behaviorist the environment directly shapes behavior and learning as opposed to any attributes or mental processes of an individual. However, over time behaviorism drew criticism for discounting internal cognitive processes and failing to consider how an individual learner mentally understands a stimulus (Reisberg, 2001).

Cognitivism came about as researchers attempted to address the shortcomings of behaviorism and account for the internal mental workings of a learner. Central to a cognitive approach to learning are the internal mechanisms by which a learner notices, mentally processes, and stores information. Thus, concepts such as sensory input channels, memory, and attention play a large part in developing a cognitive explanation of learning. Learning to a cognitivist, however, is more than just receiving, processing, and storing information and therefore cognitive theory further delves into more complex constructs relating to knowledge and thinking such as strategy, decision making, problem solving, and reasoning and how they affect learning (Donaldson & Knupfer, 2002; Reisberg, 2001).

Constructivism is a somewhat more modern approach that assumes learners actively construct knowledge, rather than acquire it, in individual ways and develop it with experience (“Learning Theories Knowledgebase,” 2011; Bush, 2006). Learning in this context consists of a learner engaging actively in the process and creating their own subjective representations of reality (“Learning Theories Knowledgebase,” 2011). Constructivists believe learners use their own interactions with the social and physical environment to actively construct meaning. Learners register input and match it with knowledge they have stored previously. New connections are then built as the new understanding is stored (Bush, 2006). Because this process is subjectively based, each learner interprets and constructs knowledge in a different manner and therefore each learner has a different, individualized knowledge base (“Learning Theories Knowledgebase,” 2011)

Social learning (also known as social cognitivism) could be considered a hybrid theory that draws upon components of both behaviorism and cognitivism. Whereas behaviorism emphasizes the environment as the initiator of learning and discounts the role of mental processes and conversely cognitivism minimizes the role of the environment and places the learner as the initiator, social cognitivism places emphasis on the interaction between the learner and the environment via observation and modeling (Kearsley, 2010; Skinner, 1985). Kearsley (2010) has adeptly summarized Bandura’s social learning theory as placing primary importance on observing and modeling the behaviors, attitudes, and emotional reactions of others. Social learning theory posits that human behavior can be explained by a constant and reciprocal interaction between internal individual factors (i.e., cognitive, affective, and biological events), behavior, and environmental influences (Bandura, 2000; Kearsley, 2010). The constituent processes key to observational learning include attention and observer characteristics, retention (memory), motor reproduction, and motivation. It is because of these elements that the theory is credited with bridging cognitivism and behaviorism.

Cognitive Learning

Semantic memory is the type of memory that is the most common in terms of learning goals in education. Because cognitive approaches focus largely on how information is acquired, stored, and organized internally, the cognitive view of learning theory as a whole perhaps most thoroughly accounts for the acquisition of semantic memory and as such a large portion of the research of this kind has a basis in a cognitive approach to learning theory. Though several different theories and models exist under the cognitive umbrella, and in fact several models exist within the information processing theory to be discussed, this section will provide an overview of key basic components of cognitive architecture from a classic cognitive information processing approach on how learning is achieved. This view arguably provides the best overall explanation of how semantic memory is created and also illustrates the structural basis from which multimedia learning theory is derived.

Cognitive Information Processing Approach to Learning

The cognitive information processing view of learning likens a human learner to a computer in that humans are seen to process information similar to the way in which a computer does (Driscoll, 2005). Information processing theory describes how information is perceived, acquired, stored, and retrieved in memory (Bush, 2006). There is a series of complex stages of processing information beginning with sensory memory, followed by working memory and long-term memory. Each will be discussed in turn.

Sensory Memory and Attention

In 1960 Sperling conducted several experiments to begin to document the existence of a perceptual sensory store that registers information and holds it for a short period of time (as cited in Driscoll, 2005). Each sensory channel is assumed to have this short term store though the most documented are the visual (iconic storage) and auditory (echoic storage) systems. When a stimulus is presented it lasts for about 1 second in iconic storage and for 3 or 4 seconds in echoic storage before it fades. Sensory storage is passive and static, it does not require attendance from the learner to occur and the length of time a stimulus is held in storage can not be changed. For the information from the stimulus to pass from sensory storage into the next stage of memory it must be further processed by allocating attention to it (Sanders & McCormick, 1993).

Not all information coming into sensory store gets processed and moves to the next stage. The notion that attention acts as an information filter was put forth by Broadbent and early work by Treisman furthered Broadbent's filter theory by proposing that attention serves to attenuate stimulation (Broadbent, 1957; Driscoll, 2005; Treisman, 1960). There are four primary types of attention: selective, focused, sustained, and divided. Selective attention monitors several input channels and chooses what information to process from the environment while simultaneously ignoring other information (Driscoll, 2005; Sanders & McCormick, 1993; Wickens & Carswell, 1997). Focused attention maintains processing of a selected source through one or a few channels while not being distracted by other sources (Sanders & McCormick, 1993; Wickens &

Carswell, 1997). Sustained attention refers to remaining alert and maintaining attention over extended periods of time. Divided attention refers to performing more than one task at a time simultaneously. Though it is accepted that humans have a limited information processing ability and this ability can be exceeded when required to perform multiple tasks at one time, there are two schools of thought regarding resource availability. Single resource theory poses that there is one central source of resources from which all mental processes must draw. Multiple resource theory poses that there are several independent resource pools to draw from and this theory is the one assumed by cognitive learning theory and the cognitive theory of multimedia learning (Kahneman, 1973; Wickens, 1984).

Working Memory

The next stage after information enters and is processed through the sensory store is short term memory or what is preferred to be termed working memory. Perhaps the most commonly accepted view of how working memory functions is the Baddeley-Hitch model which replaced the early more linear model introduced by Atkinson and Shiffrin (1971) which did not account for the complexity within the stages of memory. Baddeley (1992) describes working memory as a three part system that works to provide simultaneous temporary storage and manipulation of the information required for complex cognitive tasks including language comprehension, learning, and reasoning. The three subsystems comprising working memory are the central executive and two slave systems operating under the control of the central executive, the visuospatial sketch pad and the phonological loop. The central executive serves to control and regulate cognitive processes and its tasks include coordinating the information from the slave systems, controlling attention, and dividing attention between multiple tasks (Baddeley, 1992; Baddeley, 2000). The visuospatial sketch pad is an active store for holding and manipulating visual images and the phonological loop is an active store for holding and rehearsing speech based information (Baddeley, 2000). More recently Baddeley (2000) added a fourth component to the model, the episodic buffer, which is thought to provide an interface between the visuospatial sketch pad and the phonological loop slave systems and long term memory. The episodic buffer is a temporary storage system with limited capacity that is capable of integrating information from different sources. It is controlled by the central executive, which as a result takes on the additional task of binding into coherent episodes information from a number of sources (Baddeley, 2000).

The capacity of working memory was first investigated by Miller in 1956. Miller arrived at the "magical number" of 7 ± 2 to indicate the maximum amount of items a human can hold in working memory at a time. It is important to note however that humans can use what is called chunking in order to group information regardless of size into units to be recalled as one entity (Sanders & McCormick, 1993). Therefore, the capacity of working memory is presumed to be 7 ± 2 chunks (Miller, 1956; Sanders & McCormick, 1993). Miller's magical number was the accepted standard for a number of years, however and recent work suggests that the number of chunks that can be held in working memory is more on the average of 4 (Cowan, 2000). Information transfers from working memory to long term memory by rehearsal and encoding. Maintenance rehearsal is simply a rote process by which information is repeated continually. Elaborative rehearsal, or encoding, is a process by which a learner thinks about what the information means and how it might relate to other information, other things in the environment, or things the learner already knows (Reisberg, 2001). Encoding makes information meaningful and relates it to what might already be stored in long term memory (Sanders & McCormick, 1993). Information is coded in three types: visual (visual representations of stimuli), phonetic (auditory representations of stimuli), and semantic (abstract representations of the meaning of stimuli). Semantic coding is of the most importance to long term memory (Sanders & McCormick, 1993).

Long Term Memory

Working memory is seen to be the gateway to long term memory. Long term memory, unlike working memory, is unlimited in capacity and serves to store information on a permanent basis. There are two recognized types of long term memory, implicit and explicit. Implicit memory is activity based and is the unconscious expression of past events in current behaviors (Reisberg, 2001). One does not engage in conscious recollection to perform a task, it is done by rote. Implicit memory can be evidenced by procedural memory and priming. Explicit memory by contrast refers to the conscious thought of prior episodes. Explicit memory can be divided into two types: episodic and semantic. Episodic memory is the memory for past events or episodes (Reisberg, 2001). Semantic memory is general information that is stored and can be recalled independently of the circumstances relating to the time or event during which the information was learned (Driscoll, 2005). Semantic memory is the type of memory most often associated with the type of learning produced in education and thus is the primary focus of the remaining portion.

Once information makes its way into long term memory, it is presumed to be organized in some fashion and made available for retrieval. Many theories and viewpoints abound regarding how information is represented and organized in memory, however one of the most pervasive amongst cognitive research is schema theory. The schema concept, although not entirely new at the time, was posed by Bartlett in 1932 and was furthered by Rumelhart in 1980. Rumelhart described a schema as a data structure that represents general concepts stored in memory (Rumelhart, 1980). Collectively, schemas represent the knowledge base. A schema is further defined as "a cognitive construct that permits people to treat multiple sub-elements of information as a single element, categorized according to the manner in which it will be used" (Kalyuga, Chandler, & Sweller, 1998, p. 1). A schema can be considered a single entity containing anything that has been learned and can contain a large amount of information and is therefore not limited in its complexity. The acquisition process of schemata is active and constructive, skilled performance is developed through building increasing numbers of complex schemata by combining lower level schemata in to higher level schemata (Sweller, van Merriënboer, & Paas, 1998). In addition to organizing and storing information, schemas serve a special function of reducing cognitive load (a construct explored further in a future section) during the working memory process (Chandler & Sweller, 1996, Sweller et al., 1998). This is achieved because of its construction. Working memory is limited in capacity for elements or chunks, but the complexity of the elements is not a limiting factor in working memory. A schema, regardless of complexity, is considered as a single element. Lower level schemata incorporated into higher level schemata no longer tax working memory (Sweller et al., 1998). Schema automation is a part of schema construction and can relieve working memory taxation.

Automation occurs when tasks can be carried out with minimal conscious effort as a result of practice, thus little processing must be done in working memory (Paas, Tuovinen, Tabbers, & Van Gerven, 2003; Sweller et al., 1998).

Sweller et al. (1998) provide an excellent summary of human cognitive architecture:

> We have a limited working memory that deals with all conscious activities and an effectively unlimited long-term memory that can be used to store schemas of varying degrees of automaticity. Intellectual skill comes from the construction of large numbers of increasingly sophisticated schemas with high degrees of automaticity. Schemas both bring together multiple elements that can be treated as a single element and allow us to ignore myriads of irrelevant elements. Working memory capacity is freed, allowing processes to occur that otherwise would overburden working memory. Automated schemas both allow fluid performance on familiar aspects of tasks and – by freeing working memory capacity – permit levels of performance on unfamiliar aspects that otherwise might be quite impossible (p. 258)

Multimedia Learning

Multimedia learning can be defined as the presentation of educational material via multiple media, most often visual and auditory (Cook et al., 2009). Multimedia learning has been influenced by two primary theoretical frameworks: cognitive load theory and the cognitive theory of multimedia learning. Within these theories, working memory is the component of human cognitive architecture that plays the most pivotal role (Schmidt-Weigand, 2009). This section will begin with a discussion of cognitive load theory and a review of empirical support for the theory. This discussion is followed by the cognitive theory of multimedia learning and how elements of cognitive learning theory and cognitive architecture have been incorporated into and influence the cognitive theory of multimedia learning. A review of empirical support for the cognitive theory of multimedia learning follows. The section closes with the purpose for the current study.

Cognitive Load Theory

Many definitions and descriptions of cognitive load theory have been offered. Clark, Nguyen, and Sweller (2006) offer a succinct definition of cognitive learning theory as being a universal set of evidence-based learning principles that use what is known about human learning processes to produce efficient instructional environments. Chandler and Sweller (1991) describe cognitive load theory as a theory suggesting that instructional materials that are effectively designed facilitate learning by directing cognitive resources toward activities relevant to the material to be learned rather than toward irrelevant activities which can impede learning. Cognitive load theory is defined by Paas et al. (2003) as regarding the development of methods of instruction that efficiently use the limited cognitive processing ability possessed by humans to stimulate their ability to apply and transfer acquired knowledge and skills to new situations. Most simply put, cognitive load theory is a theory that seeks to combine human cognitive architecture and instructional design (Sweller, 2005a).

Following what is known about memory and its architecture as outlined in the previous section, cognitive load theory is based on the assumption that there exists a cognitive architecture consisting of a limited working memory (containing partly independent processing units for auditory/verbal information and visual/spatial information) interacting with an unlimited long term memory (Cook et al., 2009; Paas, Tuovinen, et al., 2003). According to cognitive load theory, the design of instructional methods must consider how working memory is constructed and thus limited and ultimately strive to create and automate schemas (Paas, Tuovinen, et al., 2003). Most basic, a learner does so best when instruction is in line with cognitive architecture. Key to a learner developing the ability to apply and transfer the skills and knowledge they acquire are the schema construction and automation processes (Paas, Tuovinen, et al., 2003). Cognitive load theory holds that through chunking, multiple elements of information can be grouped into single elements in schemas and these schemas can be automated (Paas, Tuovinen, et al., 2003). Once schemas become automated, they then reduce taxation as they bypass working memory and its limitations (Paas, Tuovinen, et al., 2003). However, in order for schemas to be created, first information must pass through and be processed and extracted from working memory. With this consideration in mind, work done within a cognitive load framework focuses on efficiency in terms of cognitive cost rather than only effectiveness, that is it considers working memory capacity in instruction and uses it to produce learning results faster and with reduced mental stress (Kalyuga, 2007; Paas, Tuovinen, et al., 2003). Efficiency in the context of cognitive load theory is defined in terms of learner performance and learner mental effort (Clark, Nguyen, & Sweller, 2006).

Cognitive Load

Defining Cognitive Load

Cognitive load is a multidimensional construct representing the load that the performance of any certain task imposes on a learner's cognitive system and refers to the demand for working memory resources during the learning procedure (Cook et al., 2009; Paas & van Merriënboer, 1994). Cognitive load is crucial in learning complex tasks and is a primary factor in the success of learning instruction, therefore the management and control of cognitive load is central to cognitive load theory (Paas, Tuovinen, et al., 2003). Paas, Tuovinen, et al. (2003) note that the amount of information learned and the complexity of that information is affected by the amount of working memory resources devoted to it and performance degrades when working memory is over or under loaded.

Types of Cognitive Load

Cognitive load can be divided into three types: intrinsic, extraneous, and germane. Intrinsic cognitive load refers to the complexity of the material to be learned and the working memory demand imposed by this complexity is intrinsic to the material to be learned (Paas, Renkl, & Sweller, 2003). This complexity is measured as a function of the interaction between element interactivity and task specific learner experience. Element interactivity is the number of different types of information learners must process simultaneously and integrate in order to understand the material. Intrinsic cognitive load is the type of cognitive load that is least able to be directly influenced or changed and as such can pose an impediment to learning in and of itself (Cook et al., 2009; Kalyuga, 2007; Paas, Tuovinen, et al., 2003). Germane cognitive load refers to activities in the learning process that are designed to promote schema acquisition and automation, thus reducing working memory resource taxation during the learning process and enhancing learning (Cook et al., 2009; Kalyuga, 2007; Paas, Tuovinen, et al., 2003). Or rather, it is the mental load that results from the instructional activities that are pertinent to the learning goal (Clark et al., 2006). In contrast, extraneous cognitive load is essentially a result of poor instructional design and refers to instructional variables that misallocate cognitive resources to material irrelevant to learning thus reducing the available resources (Cook et al., 2009; Kalyuga, 2007; Paas, Tuovinen, et al., 2003). Cognitive load theory considers intrinsic, germane, and extraneous cognitive load as additive, though not equal parts, and together they comprise overall cognitive load (Paas, Renkl, et al., 2003; Paas, Tuovinen, et al., 2003). Total cognitive load in an instructional design should not exceed working memory capacity in order for efficient learning to occur (Kalyuga, 2007; Paas, Renkl et al., 2003; Paas, Tuovinen, et al., 2003).

As noted, the relationship between the three types of cognitive load is additive, though unequal, to provide overall cognitive load. The base load is provided by intrinsic load which is not reducible, except in cases where schemas are constructed and automation of previous schema occurs thus changing the level of learner experience or expertise (Paas, Renkl, et al., 2003). After the intrinsic load is established and available cognitive resources are allocated to it, the remainder of the available cognitive resources are directed to extraneous and germane load. Extraneous and germane load can have a reciprocal relationship, when one load is reduced, it leaves more cognitive resources for the other (Paas, Renkl, et al., 2003). High intrinsic load as indicated by high element interactivity and low learner experience and insufficient schemata, however, can leave few resources to be allocated to extraneous and germane load (Bannert, 2002). The goal of instructional design according to cognitive load theory is to make use of germane cognitive load to foster learning while reducing extraneous load and managing intrinsic cognitive load to leave sufficient working memory capacity for learning (Clark et al, 2006).

Dimensions of Cognitive Load

Cognitive load has two dimensions: causal and assessment. The causal dimension reflects learner and task/environmental characteristics and their interaction. Learner characteristics are relatively stable and include cognitive abilities, cognitive style, preferences, prior knowledge, expertise level, age, and spatial ability (Kirschner, 2002; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994). Task characteristics include task format, task novelty, time pressure, task complexity, use of multimedia, pacing of instruction, and reward systems and environmental characteristics include noise and extreme temperatures (Kirschner, 2002; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994).

The assessment dimension reflects three measurable aspects of cognitive load: mental load, mental effort, and performance. Mental load is the load expected to be imposed on cognitive resources from the interaction of subject and task/environmental demands (Cook et al., 2009; Paas, Tuovinen, et al., 2003). Mental load is thus an *a priori* estimate of cognitive load (Paas, Tuovinen, et al., 2003). Mental effort refers to the actual amount of cognitive resources or capacity that is allocated to the task demands and as such reflects actual cognitive load (Cook et al., 2009; Kirschner, 2002; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994; Sweller et al., 1998). Performance, the learner’s performance on a task, reflects mental load, mental effort, as well as the three causal factors (Cook et al., 2009; Kirschner, 2002; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994; Sweller et al., 1998).

Measuring Cognitive Load

Historically, cognitive load measurement techniques have been classed in three primary categories. These categories encompass subjective, physiological, and task and performance based indices and are empirical in nature; however analytical measures are also used in cognitive load measurement (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994; Sweller et al., 1998). Analytical methods are those that are used to estimate cognitive load and thus are meant to be predictive or evaluative (Cook et al., 2009; Paas, Tuovinen, et al., 2003). Analytical methods collect subjective data to provide an *a priori* estimate of mental load through techniques such as task analysis, mathematical models, and expert opinion and should be further supported by empirical data (Cook et al., 2009; Paas, Tuovinen, et al., 2003).

Subjective techniques are typically self-report rating scale questionnaire measures and rely on the assumption that a learner can introspect on their own cognitive processes and provide an account of their expenditure of mental effort (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994; Sweller et al., 1998). Gopher and Braune (1984) have demonstrated that learners are indeed capable of introspection and can assign numerical values to their mental effort giving such self-report rating scales value in their use as a measurement methodology. Many self-report rating scales to assess mental workload are in existence. Some well utilized examples include the Subjective Workload Assessment Technique (SWAT) developed by Reid and Nygren (1988), the NASA Task Load Index (NASA-TLX) developed by Hart and Staveland (1988), the Multiple Resources Questionnaire (MRQ) developed by Boles and Adair (2001), and the Subjective Cognitive Load Measure (SCL) first adapted and developed by Paas (1992). The SWAT was developed in order to provide a psychological model of mental workload and is based on an overall additive multidimensional representation of psychological stress load, mental effort, and time load (Nygren, 1991). Perhaps the most widely used scale to assess overall subjective workload is the NASA Task Load Index (NASA-TLX) developed by Hart and Staveland (1988). The NASA-TLX is a multidimensional scale and includes six subscales regarding various aspects of task experience from which an overall workload score is derived (Hart & Staveland, 1988). The six subscales are mental demand, physical demand, temporal demand, performance, effort, and frustration. The average of the six subscales is weighted to reflect the rater's perspective of how each factor contributes to the workload and this weighted average provides an overall workload score (Hart & Staveland, 1988). The MRQ is another subjective workload measurement tool, however rather than providing an overall assessment of workload as do the SWAT and NASA-TLX, the MRQ takes a multiple resources approach and provides independent assessments of multiple mental resources (Boles, 2007; Boles & Adair, 2001a, Boles & Adair, 2001b). The SCL was developed in response to the development of cognitive load theory and measures overall load (Wiebe, Roberts, & Behrend, 2010).

Physiological techniques include measures of heart, brain, and eye activity and these techniques assume that changes in physiological variables reflect changes in cognitive processing (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Paas & van Merriënboer, 1994; Sweller et al., 1998). Paas, Tuovinen, et al. (2003) indicate that physiological measures are particularly useful as a means to envisage the trend and pattern of cognitive load. Although argument exists regarding the effectiveness of using physiological measures to assess cognitive load, Cook et al. (2009) contend that physiological measures are more objective and are less likely to contain the level of measurement error as that which can be associated with either subjective or task and performance based techniques.

Task and performance based techniques are divided into two subclasses: primary and secondary task methodologies (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Sweller et al., 1998). Primary task measurement is based on task performance and methodologies for measurement typically include the performance variables of accuracy and response time on measurement tools that assess the learning of information from instructional materials (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Sweller et al., 1998). Secondary task methods are based on the performance of a simultaneously performed second task. Secondary tasks commonly include relatively simple sustained attention tasks involving quickly and accurately detecting either auditory or visual signals. Secondary tasks are intended to reflect the cognitive load imposed by the primary task; the rationale being as a primary task increases in difficulty, there are fewer resources available for performing the secondary task (Cook et al., 2009; Paas, Tuovinen, et al., 2003; Sweller et al., 1998).

Cognitive Load Theory, Managing Cognitive Load, and Instructional Design

The ultimate goal of learning is to create schemas and schema automation in long term memory and in order for learning to occur, working memory capacity during the learning process must not be exceeded. If total cognitive load is such that it exceeds working memory capacity, learning is impaired. Thus, the management of cognitive load is necessary to avoid over-taxation of working memory by ensuring sufficient resources are left available to direct to learning. As the inappropriate design of learning materials is often the cause of cognitive overload during the learning process, strategies for reducing cognitive load have typically focused on the external management of the three types of cognitive load through instructional design. However, though beyond the scope of the current research, it should be noted that an additional approach that focuses on an internal means of cognitive load management achieved through the development of adequate learning strategy has been reported in the literature (Bannert, 2002).

Effects of Cognitive Load

The inappropriate design of learning materials can cause increased extraneous cognitive load which in turn can leave insufficient resources for learning (Kalyuga, 2007). Strategies for reducing cognitive load have largely been focused on reducing extraneous and intrinsic cognitive load through the manipulation of instructional design. Cognitive load theory has been used to identify and explain through research several effects of cognitive load caused by poorly designed instructional materials. The identification of these effects has given rise to procedures for reducing extraneous cognitive load to enhance learning (Chandler & Sweller, 1996). These effects include the goal free effect, the worked example effect, the expertise reversal effect, the completion problem effect, the variability effect, the split attention effect, the modality effect, and the redundancy effect. Of particular relevance to the presentation of multimedia instruction are the split attention, redundancy, modality, and expertise reversal effects and as such these effects will be described in detail (Low, Jin, & Sweller, 2009).

Split attention occurs under the circumstances when a learner is presented with either physically or temporally separated information from multiple sources where each information source is critical to the understanding of the material to be learned. The learner is then required to mentally integrate these separated sources and the imposition on working memory caused by the requirement to integrate increases extraneous cognitive load and impedes learning (Chandler & Sweller, 1996; Low et al., 2009; Sweller et al, 1998). The split attention effect is a result of the prediction that integrated formats of instruction will prove to be superior in experiments when compared to split attention formats (Chandler & Sweller, 1996; Low et al., 2009; Sweller et al, 1998). The body of empirical support giving rise to this expectation began with research conducted by Tarmizi and Sweller in 1988 and the effect has been found in numerous studies in multiple domains (as cited in Chandler & Sweller, 1996; Low et al., 2009; Sweller et al, 1998). Ayers and Sweller (2005) provide a review of research regarding the split attention effect. Ayers and Sweller cite experiments by Tarmizi and Sweller that resulted in learners who studied integrated worked examples of geometry problems producing fewer errors and faster solution times than learners who used a traditional problem solving strategy. Ayers and Sweller describe other studies in the mathematical domain producing similar results supporting integration under the split attention effect. Sweller, Chandler, Tierny, and Cooper (as cited in Ayers & Sweller, 2005) were able to replicate Tarmizi and Sweller's results using coordinate geometry. Ward and Sweller (as cited in Ayers & Sweller. 2005) showed that learners studying integrated worked examples of physics problems performed better than both those using a problem solving strategy and those using a worked example that was structured traditionally. Further, Chandler and Sweller (as cited in Ayers & Sweller, 2005) demonstrated that learners using integrated texts and diagrams to study electrical installation performed better than those using non-integrated texts and diagrams. Ayers and Sweller caution that there are conditions under which the split attention principle advocating integration does not apply or can have detrimental effects on learning. First, the split attention principle only applies when the multiple sources of information being presented can not be understood if presented independently. Second, the principle only applies when the material being presented is high in element interactivity. Third, the learner knowledge level influences whether the information sources are independently understood or high in element interactivity. To those with high knowledge, applying the split attention principle could negatively affect learning resulting in an expertise reversal effect.

The redundancy effect provides evidence to the contrary that all split sources information should be integrated. The redundancy effect occurs when there are multiple sources that each contain all the information critical to learning the material and can be used without any reference to each other (Chandler & Sweller, 1996; Low et al., 2009; Sweller et al, 1998). When such redundant sources are presented, learning can be compromised because the redundant information occupies working memory capacity thus leaving less available for learning. Extraneous cognitive load is reduced and learning is facilitated as a result of removing independently understood redundant sources. Sweller (2005b) indicates that redundant information can be presented to learners in two ways. First, redundant information can be delivered via multiple forms or media. For example, the information can be given in text as well as in a diagram. In the second method, redundant information can be given as a result of an attempt at providing additional information for elaboration or enhancement. An example of this method is presenting a full elaborated text rather than a concise summary of the text (Sweller, 2005b). There are several factors to consider when determining what information is deemed redundant. These include whether the sources are intelligible independently, if each sources adds essential information, whether the source is high in element interactivity, and learner experience

(Sweller, 2005b). Sweller (2005b) provides a review of research pertaining to the redundancy effect. Though examples of the redundancy effect in research can be found as far back as the 1930s, the redundancy effect named as such was found by Chandler and Sweller (as cited in Sweller, 2005b) as a result of their work investigating the split attention effect. Chandler and Sweller presented learners with information regarding blood flow in the heart, lungs, and body. The information presented in only a diagram proved superior to a diagram with integrated text. Bobis, Sweller, and Cooper (as cited in Sweller, 2005b) found similar results demonstrating that a diagram without integrated text resulted in better learning when teaching a basic geometry paper folding task to elementary school students. Further, the authors found that adding additional diagrams depicting different perspectives of the task decreased learning. Kalyuga, Chandler, and Sweller (as cited in Sweller, 2005b) were able to demonstrate not only the redundancy effect but also the modality effect. The authors presented either a diagram and written text or a diagram with spoken text and found that the diagram and spoken text was better for learning than the diagram and written text. Further, a diagram with spoken text was better than a diagram, spoken text, and identical written text together. The written text was redundant.

Whereas the split attention and redundancy effects reduce extraneous cognitive load by freeing resources through the minimization of unnecessary cognitive activities, the modality effect decreases extraneous cognitive load by increasing effective working memory capacity (Low et al., 2009; Sweller et al, 1998). This effect assumes the multiprocessor theory of working memory described previously. The modality effect is one that derives from the split attention effect and arises under split attention conditions in which a written source of information that must be integrated by the learner with another visually presented source is presented instead in auditory form (Low et al., 2009; Sweller et al, 1998). The modality effect occurs when learning material presented dually in part visual and part auditory modes results in greater effectiveness than when material is presented in a visual or auditory only mode (Low et al., 2009; Sweller et al, 1998). Presenting material designed to split the load across more than one input channel in working memory prevents the overload of any one channel. Low and Sweller (2005) review research investigating the modality effect. Research demonstrating the modality effect can be found as far back as the 1970s. More recently, Mousavi, Low, and Sweller (as cited in Low & Sweller, 2005) found supportive evidence for the modality effect when they presented instructions for geometry in either diagram and written text form or in diagram and auditory text form. A diagram presented with spoken text repeatedly proved better for learning over a series of experiments done by the authors. Tindall-Ford, Chandler, and Sweller (as cited in Low & Sweller, 2005) also produced similar findings using electrical engineering instruction. However, Tindall-Ford, Chandler, and Sweller expanded their study to also differentiate between low and high element interactivity instructional materials. The authors found support for their hypothesis that low element interactivity materials which are also low in intrinsic cognitive load would not display the modality effect. This is because with low element interactivity materials working memory is not over-taxed and the need to employ measures to increase working memory capacity is unnecessary. Leahy, Chandler, and Sweller (2003) found support for the modality principle in addition to noting that the effect could only be obtained when the information presented by both the visual and auditory modalities was essential for understanding the material.

The effects of cognitive load described previously offer methods for freeing working memory by reducing extraneous cognitive load during the learning process. However, it is important to note that reducing extraneous load is a tactic beneficial to novice learners rather than expert learners. Novice learners lack the schemas that expert learners have already developed in their long term memory and therefore require a schema substitute in order to compensate (Cook et al., 2009). Learning environments that are designed to free working memory capacity for learning of the material become the schema substitute to support learning (Cook et al., 2009). Because expert learners already possess the necessary schemas, they then rely on these schemas to support further learning and do not require support in the form of instructional design as novices do. Since schemas allow learners to bypass working memory, techniques to manipulate the instruction so that working memory is freed are unnecessary for experts and in fact can negatively impact learning for experts, an effect known as expertise reversal (Cook et al., 2009; Kalyuga, Ayres, Chandler, & Sweller, 2003). This expertise reversal effect is the result of an expert learner cognitively attending to an unnecessary source, thus inhibiting learning by occupying resources in working memory (Low & Sweller, 2005; Kalyuga et al., 2000). Sources become redundant or unnecessary as expertise increases, therefore techniques used for reducing cognitive load such as delivering information via two different modalities are most likely to aid novices to whom the additional sources are necessary to achieve understanding and cognitive load reduction (Kalyuga, 2007; Kalyuga & Sweller, 2004; Sweller, 2005a).

Empirical Support for Cognitive Load Theory

Kalyuga, Chandler, and Sweller (1999) conducted two experiments in order to investigate the management of split attention and redundancy. The goal of the first experiment was to determine whether increasing effective working memory by changing the modality of the instruction could provide an alternative to the integration of sources recommended to reduce cognitive load associated with split attention. Participants were randomly assigned to one of three condition groups. The task to be learned was how to use a fusion diagram to determine solder states. One group received sequentially introduced animated components of the diagram along with written explanations of newly appearing elements and simultaneously presented auditory explanations identical to the written explanations. Another group received sequentially introduced animated components of the diagram along with written explanations of newly appearing elements. The final group received sequentially introduced animated components of the diagram along with auditory explanations of the diagram. All groups first received a self-paced introductory presentation to introduce the diagram. Learners in all conditions were given seven interactive exercises with immediate feedback and hints. This was done to collect reattempt data to differentiate between groups and to prepare the learners with basic concepts before the more complicated second phase. The second phase of this first experiment required the participants to study descriptions of major features of specific solders. The descriptions were delivered in the same condition group formats as phase one. Participants rated subjective mental workload after studying the descriptions and then completed a test phase requiring the participants to identify faults on a diagram in order to determine understanding of soldering instructions. Next, the participants completed a multiple choice test concerning the material given in the descriptions of major features of specific solders. It was predicted that the modality effect would be found for the group receiving visual animation and written explanations and the group receiving visual animations with auditory explanations. The group receiving visual animations, written explanations, and auditory explanations was expected to experience higher cognitive load and learning interference due to redundancy. It was found in experiment 1 that modality may be used to combat split attention problems. The instruction group using audio explanations with visual animations had fewer reattempts, lower cognitive load ratings, and higher test performance scores than the other two groups. In addition, the redundancy effect was shown when the group receiving visual animations, written explanations, and auditory explanations experienced significantly higher cognitive load and lower performance than the other groups.

Experiment 2 of Kalyuga, Chandler, and Sweller’s (1999) study sought to determine whether color coding of text and diagrams could reduce cognitive load associated with split attention conditions. It was expected that color coding written text with the corresponding relevant diagram sections would reduce search processes for the learner and result in a reduction of working memory load. Participants were randomly assigned to either a conventional format condition for explaining an electrical circuit consisting of a diagram with a written text explanation below it or a color coded condition consisting of the same diagram with written text below but by clicking on any paragraph in the text in this condition, it was highlighted in a unique color along with the corresponding elements of the diagram. Participants were self paced and did not have any time restrictions. After studying the electrical circuit in their assigned conditions, participants rated subjective mental load. They were then given a fault finding test and then a multiple choice test relating to the operation and function of the circuit. It was reported that those in the color coded group showed marginally lower mental load scores. However, this group showed significantly higher multiple choice test scores than the conventional group. The authors attribute this effect to a reduction in cognitive load evidenced by the mental load rating scores.

Kalyuga, Chandler, and Sweller (2004) conducted a series of three experiments in order to investigate the effects of redundant on screen text. Experiment 1 sought to compare the effects of concurrent auditory and visual information (diagram with auditory and written text) with sequential auditory and visual information (diagram with audio text and delayed written text). It was expected that the sequential presentation of redundant written and auditory text would not have the same detrimental cognitive load effects as concurrently presented auditory and written redundant text. This prediction was made in following with cognitive load theory which suggests that because the two sources of redundant information are not presented at the same time, cognitive resources should not be as taxed as they would be if trying to mentally integrate the redundant information when presented at the same time. After random assignment to the conditions, participants studied cutting speed nomogram information presented as determined by their treatment group. The studying was self-paced and not timed though time spent on the task was recorded. Participants then subjectively rated task difficulty and then were given multiple choice questions based on the material studied. Significant differences were found for mental load and instructional efficiency such that the sequential condition resulted in lower cognitive load and higher instructional efficiency than the concurrent condition. However, no significant difference was found for performance. The authors attribute this to the possibility that because the task was not timed, learners had prolonged exposure to the visual information and this extra exposure could have compensated for the cognitive load imposed by the redundant information.

In the second experiment by Kalyuga, Chandler, and Sweller (2004), the effects of concurrent auditory and visual information (animated diagram with auditory and written text) with sequential auditory and visual information (animated diagram with audio text and delayed written text) were again compared but in this experiment the amount of time the participants had to study the material was limited. Participants were randomly assigned to conditions and then studied soldering characteristics information delivered as dictated by condition. Participants then subjectively rated task difficulty and then were given multiple choice questions based on the material studied. It was determined that the sequential condition produced significantly lower mental load scores, significantly higher performance scores, and significantly higher instructional efficiency scores. These results confirmed a redundancy effect in the concurrent condition. The authors point out that when providing written text after giving auditory text, the written text might serve as a form of revision of the material learned in the auditory presentation. In order to determine whether a redundancy effect would still be observed without the delayed written text serving as revision, a third experiment was conducted.

In experiment 3 by Kalyuga, Chandler, and Sweller (2004), information regarding basic mechanical engineering was presented in either concurrent auditory and written form or in auditory only format. It was expected that the auditory only condition should eliminate the redundancy effect and reduce cognitive load. After random assignment to conditions, participants received instruction in accordance to their assignment. Following instruction, participants rated their mental load then completed a multiple choice test. No significant difference was found in mental load, however instructional efficiency and performance were significantly better in the auditory alone condition. These results confirm the redundancy of concurrent auditory and written information.

Kalyuga, Chandler, and Sweller (1998) conducted a series of three experiments in order to investigate the split attention and redundancy effects as they relate to novice and expert learners. The first experiment compared integrated diagram and written text, separate diagram and written text, and diagram only formats with novice learners. It was expected that the integrated diagram and text would be superior to the other formats. Participants were randomly assigned to the conditions and participated in two instruction phases and two test phases, the first for learning electrical switching for a bell and light circuit and the second for an electrical circuit of a water pump. In each phase participants received self-paced instruction in the formats designated by their assigned conditions then completed subjective mental effort scales. Each instructional phase was then followed by a three part test phase. Part 1 of the test phase consisted of reproduction tasks relating to the information learned, part 2 consisted of questions relating to the information learned, and part 3 contained fault finding exercises. Experiment 1 yielded support for the hypothesis. The integrated diagram and written text format required significantly less subjective mental effort than the diagram only group for both phases and significantly less subjective mental effort than the separate diagram and text for phase 1. There were no significant differences between the groups for reproduction tasks for either phase. However, the integrated diagram and text group performed significantly higher on the function and operation tests than both the separate diagram and text and diagram only groups in phase 1 and significantly higher than the diagram only group in phase 2. The integrated diagram and text group performed significantly better on the fault finding task than the diagram only group in phase 1 and significantly better than both other groups in phase 2. It was also found that integrated diagram and text instructional format was more efficient than the other formats as is consistent with cognitive load theory.

Kalyuga, Chandler, and Sweller’s (1998) second experiment sought to compare the same formats as experiment 1 using participants relatively inexperienced in electrical circuits and also sought to compare these formats again after the participants were given more extensive training on the subject. It was predicted that prior to receiving extensive training, the integrated diagram and text would be best for initial learning and the diagram only format would be best for the participants once experienced. Participants were randomly assigned to the three conditions. The experiment was conducted in three stages. In stage 1 the participants received timed electrical instructions of a motor with a starter presented according to their condition. They were then given a subjective mental load measure and asked fault finding questions and multiple choice questions regarding function and operation. In stage 2, the participants were given extensive training in electrical circuitry with a diagram and written text format. During instruction, written text appeared in turn on the screen in proximity to the corresponding diagrammatical information and as the material was introduced, both the relevant text and diagram sections were highlighted and an animation was shown showing changes in the circuit state. This instruction was self-paced and participants were able to repeat instruction as needed. Stage 3 proceeded precisely as stage 1. Results indicated that as expertise increased, performance by the participants in the diagram only group improved more than the other groups. However, the authors report that the expected full redundancy effect with significantly superior performance of the diagram only text was not found. This was attributed to the participants possibly not achieving the level of expertise necessary to make written text redundant.

Experiment 3 by Kalyuga, Chandler, and Sweller (1998) sought to create the level of expertise necessary to expect written text with a diagram to be redundant. The same participants from experiment 2 were assigned to either a diagram only or an integrated diagram and written text group. In stage 1 of the two stage experiment, participants received direct electrical circuitry training. Instructional materials were presented with auditory text coordinated with animations and highlights of appropriate elements of the circuits. The instruction was self-paced and repeatable and also contained interactive training exercises with hints and feedback. In stage 2, the participants were required to study an electrical circuit slightly different from what was studied in stage 1. Participants studied the materials as presented in their assigned format for a limited time. Subjective mental load ratings were then collected and a fault finding test and multiple choice operation and function test was then given. The diagram only format proved to be more efficient as an instructional technique for experts than the diagram and text format. Results also yielded significant differences between the groups demonstrating that the diagram only group showed lower subjective mental load, higher performance scores, and faster instruction processing time.

Kalyuga, Chandler, and Sweller (2000) conducted two experiments in order to investigate the modality and redundancy effects as they relate to novice and expert learners. The first experiment used novice learners to compare animated diagram with written text, animated diagram with auditory text, animated diagram with written and auditory text, and non-animated diagram only conditions. Based on the modality effect in the cognitive load theory, it was predicted that the diagram and auditory text format would return better performance than the diagram and visual text format. Based on the redundancy effect, it was predicted that the diagram with written and auditory text would impose a higher cognitive load than the diagram and auditory text format and inhibit performance. It was also expected that more experienced participants would benefit most from the diagram only format. Participants were randomly assigned to the conditions and the material to be learned regarded a cutting speed nomogram. In stage 1, participants studied the material as delivered by their treatment condition in a self-paced and untimed manner. Subjective task difficulty ratings were then collected and then multiple choice questions were asked to serve as performance data. Following the performance test, the participants were given a training session in using the cutting speed nomogram. A worked example was presented that used written text explanations of the nomogram. Participants were allowed to study the material as long as they felt necessary and then were given a self-paced multiple choice test with automatic feedback after each question. Stage 2 began with another training session consisting of more multiple choice questions similar to those used in the training session in stage 1. Following the training session, participants were again given instruction in their assigned conditions; however a different and more complicated representation of the nomogram was used for instructional material. Following instruction, participants gave subjective mental load ratings and completed a multiple choice performance test. As hypothesized and in confirmation of the modality effect, it was found that novices performed significantly better with an animated diagram and auditory text and had lower mental load than those novices using an animated diagram with written text. In confirmation of the redundancy effect, it was found that those using the animated diagram and auditory text performed significantly better than those using the animated diagram with written and auditory text. With experienced learners, the experiment showed in learners using a diagram only an increase in performance greater than that of users of the other groups. However, statistical significance was not found. This was attributed to the possibility that learners were allowed uninterrupted time to study the diagram and could skip the auditory and written explanations if they wished rendering the conditions equivalent in delivery.

Experiment 2 of the series by Kalyuga, Chandler, and Sweller (2000) sought to eliminate the possibility of uninterrupted study of the diagram without attending to the verbal explanations. A diagram only and diagram with auditory instruction regarding a different version of the cutting speed nomogram were compared using the same participants from experiment 1. It was predicted that the participants would be more experienced in using nomograms than in experiment 1 and would perform better with the diagram only. Participants began with a training session consisting of worked examples regarding the instructional material presented in diagrams with written explanations. Each worked example was followed by a multiple choice question with immediate feedback. Participants were then given timed instruction in their assigned condition and subjective measures of mental load and multiple choice performance data were collected. Those using only the diagram performed significantly better than those using the diagram and auditory text and the diagram and auditory format was rated more difficult. In experiment 2, a redundancy effect was obtained due to the increased cognitive load imposed by the auditory explanation.

Rey and Buchwald (2011) investigated the occurrence of the expertise reversal effect under redundancy conditions and the possible cognitive load and motivational explanations for the expertise reversal effect. Participants received either animated graphical depictions with explanatory textual passages or animated graphical depictions without the textual passages. It was hypothesized that the expertise reversal effect would be replicated as a result of redundancy. More specifically, novices would perform better when given an animation and additional textual information than novices given only the animation. Experts who receive an animation with textual information were expected to perform worse than experts given only the animations. It was also hypothesized that novices receiving additional information would exhibit higher motivation and lower cognitive load than novices not receiving additional information and experts receiving additional information would exhibit lower motivation and higher cognitive load than experts not receiving additional information. Participants were randomly assigned to either expert or novice groups receiving either additional textual information or no additional textual information. Those in the expert group received additional training during experimentation to induce expertise in gradient descent procedure. All participants received an instructional page of information and then received an introductory presentation regarding gradient descent followed by a motivation assessment questionnaire. Those assigned to the expert conditions then received a text page and animations either with or without on screen explanations according to condition and were then given a learning test to verify expertise induction. Next all participants were given animated instruction either with or without additional on screen textual information according to condition. Following instruction all were given a final text page providing two alternative solutions to solve problems that arise when applying the gradient descent procedure. Finally, retention, transfer, cognitive load, motivation, and demographics questionnaires were presented. It was found that the expertise reversal effect was replicated due to redundancy as hypothesized such that novices receiving additional information performed significantly higher on retention and transfer than novices who didn’t receive the additional information. Experts who received additional information performed worse on retention and transfer than those experts not receiving additional information. No significant interaction was found between expertise level and additional information in relation to motivation suggesting that motivational differences appear not to sufficiently explain expertise reversal as a function of redundancy. However, a significant interaction between expertise level and additional information was found for cognitive load indicating that expertise reversal as a function of redundancy could be explained by differences in cognitive load. Novices receiving the additional information demonstrated significantly lower cognitive load ratings than those novices not receiving the additional information, and the reverse was observed for experts as hypothesized.

Cognitive Theory of Multimedia Learning

The cognitive theory of multimedia learning is a learner centered approach to multimedia design which serves to generate and evaluate instructional design principles aimed at improving the effectiveness of multimedia learning (Kirschner, 2002). The cognitive theory of multimedia learning draws upon dual coding theory, cognitive load theory, and constructivist learning theory and from these theories three assumptions on which the cognitive theory of multimedia learning are based are obtained (Cook et al., 2009). From dual coding theory the notion that within working memory there are two systems to independently encode and process visual and auditory information is taken. The visual channel produces pictorial representations from input from the eyes and the auditory channel takes input from the ears and produces verbal representations

(Cook et al., 2009; Mayer & Moreno, 2002). Taken from cognitive load theory is the notion that working memory capacity is limited, the resources allocated to the visual and auditory channels are limited and when demand exceeds availability, cognitive overload can occur resulting in some information not being processed at all (Cook et al., 2009; Mayer & Moreno, 2002). And from constructivist theory, the idea is taken that for meaningful learning to occur, a learner must actively select and process information from both channels simultaneously then organize the information into coherent verbal and visual representations and integrate the information with prior knowledge in corresponding existing schemas (Cook et al., 2009; Mayer & Moreno, 2002). Mayer and Moreno (2003) define meaningful learning as a deep understanding of the learned material. Therefore, within a cognitive theory of multimedia learning framework, the goal of multimedia instructional design is to reduce cognitive load by properly organizing and integrating visual and auditory information thus leaving the learner with more cognitive resources to integrate newly learned material with that retrieved from schemas in long term memory (Cook et al., 2009). Conversely, poor designs can impede a learner and increase cognitive load.

Instructional Design Principles

From the cognitive theory of multimedia learning, a number of instructional design principles to guide and promote multimedia learning have been derived and tested. These principles are methods by which instructional designers can reduce extraneous cognitive load, manage intrinsic cognitive load, and foster germane cognitive load (Mayer, 2009). The principles derived from the cognitive theory of multimedia learning originally included the multiple representation principle, the contiguity principle, the coherence principle, the modality principle, and the redundancy principle. More recently, the theory has expanded to further include other principles such as signaling, segmenting, pre-training, personalization, voice, and image (Mayer, 2009). In their works, Mayer (2009) and Mayer and Moreno (2002) provide a description of each and present empirical support for the derivation of each principle. The principles most relevant to the current study are the original principles and these are discussed in detail below and summarized in Table 1.

The multiple representation (multimedia) principle suggests that information should be presented in both words and pictures, rather than the most commonly employed mode of verbal only instruction. In experiments described by Mayer and Moreno (2002), learners were given instruction regarding the workings of pumps and brakes either by narration only or by narration accompanied by a corresponding animation. To determine the learning outcome, learners were given a problem-solving transfer test and the number of correct scores were totaled. Across three separate tests, students were reported to learn more deeply from narration and animation combined than from only narration. Mayer and Moreno note that this outcome is consistent with the cognitive theory of multimedia learning in that the theory holds that meaningful learning is enhanced when a learner builds representations of both verbal and visual material and connects these corresponding representations with each other and with prior knowledge held in schemas. Mayer and Moreno caution, however, that multimedia presentations are not all equally effective and offer additional conditions in the form of design principles under which deep understanding is promoted.

Mayer and Moreno (2002) detail a contiguity principle, also described in cognitive load theory as the split attention principle, which recommends that information be presented in corresponding words and pictures simultaneously rather than sequentially. This is contrary to the information delivery theory which would suggest that the verbal and pictorial presentations be given separately affording the learner two presentations of the information. However, the recommendation for simultaneous presentation stems from the assumption of the cognitive theory of multimedia learning that meaningful learning occurs when a learner builds representations of both verbal and visual material and connects these corresponding representations with each other in working memory. Learners are more likely to successfully hold corresponding visual and verbal representations in working memory when the presentations are done so at the same time, whereas working memory limitations make it unlikely that representations from successive presentations can be held at the same time. The contiguity principle includes both spatial and temporal contiguity and these are often described in the literature separately. Spatial contiguity refers to the notion that deeper learning is achieved when corresponding words and pictures are shown physically close together, reducing the need of the learner to go back and forth between the locations of the text and graphics. Temporal contiguity holds that deeper learning is achieved when corresponding animation and narration are given at the same time, thus keeping words and graphics in working memory at the same time (Mayer, 2005). Mayer and Moreno describe experiments which affirm the contiguity principle and support the cognitive theory of multimedia learning. Learners were either given instruction via narration and animation simultaneously or animation before or after narration. Across a series of eight tests, greater problem-solving transfer scores indicated that learners achieved deeper learning when presented with animation and narration simultaneously.

The coherence principle offered by Mayer and Moreno (2002) maintains that multimedia presentations should limit the addition of irrelevant embellishment, presentations are best understood when they contain fewer extraneous words and sounds. By eliminating irrelevant material, the learner is then able to direct all available cognitive resources to processing the material to be learned (Mayer, 2005). The idea behind the argument in favor of adding embellishment is that it might make the material more interesting to learners which will motivate them to learn, though Mayer and Moreno cite studies in which the addition of interesting but irrelevant material failed to improve learner memory for the target material. The argument against adding embellishment stems from the notion that the extraneous material could inhibit the learner from making connections between steps in the causal chain by filling working memory, thus leaving the learner unable to hold relevant material in working memory at the same time to build connections. In studies described by Mayer and Moreno, learners were presented with either an animation presented simultaneously with narration with no embellishment or an animation presented simultaneously with narration that included embellishment. In all three comparisons, learners who received no embellishment were able to provide more problem-solving transfer test solutions than those who received embellishment.

The modality principle posited by Mayer and Moreno (2002) states that words are best presented during multimedia instruction as narration rather than as on screen text. The cognitive theory of multimedia learning holds that the visual and verbal channels are limited in capacity and when words are presented in an on screen text format, they are initially processed via the visual channel along with the pictorial representation. This creates competition in the visual channel between the verbal and pictorial representations for attention to be processed, thus potentially causing overload in visual working memory and a loss of processing of some presented material. If words are presented through narration, the information is processed through the verbal channel rather than the visual channel. This frees resources in the visual channel for processing the pictorial information, thus increasing the opportunity for deep processing of the information received in both channels. Mayer and Moreno compared learning outcomes of learners who were presented either an animation and narration or an animation and on screen text and found that in all four comparisons, learners who received animation with narration performed superiorly to the learners presented with animation and on screen text in the problem-solving transfer test. Low and Sweller (2005) point out that the observance of the modality effect can be dependent upon certain conditions. First, the modality effect is likely to be observed only under split-attention conditions, that is when both information sources being presented are necessary in order for a learner to understand the material. It is not observed when the information sources are redundant (Leahy, Chandler, & Sweller, 2003). Next, the modality effect is not likely to be observed with low element interactivity material. This is because the elements in such material do not interact and can be processed individually, thus the modality effect is likely to be observed with high element interactivity material (Low & Sweller, 2005). Finally, the modality effect is most likely to be seen with novices rather than experts. For novices, they are likely to require both information sources in order to initially understand the material. As they become more experienced with the material, one of the sources could become redundant and the presence of this redundant source could eliminate the modality effect and even produce negative learning results for experts if they cognitively expend resources attending to it (Kalyuga et al., 2000).

The redundancy principle holds that when presenting pictorial information along with verbal information, the verbal information should be presented as narration only rather than as both narration and on screen text (Mayer & Moreno, 2002). This allows for spreading the material over both the auditory and visual channels and reducing over-taxation of the visual channel. It also prevents the learner from unnecessarily directing cognitive resources to reconciling the narration with the printed words which become extraneous material when given along with narration (Mayer, 2005). This principle is in contrast to the learning preference theory that would suggest that pictures and words be presented together with the verbal information presented as both narration and on screen text, thus allowing the learner to choose which format to attend to based on preference given the assumption that the information presented in all three manners is the same. However, when verbal information is presented on screen and in narration, a split attention effect as described above occurs. Learners must visually attend to both the narration and on screen text which could result in other information not being attended to and processed. A taxation on visual working memory creates increased cognitive load and learners might not able to successfully build the connections between the visual and verbal representations that the cognitive theory of multimedia learning holds is necessary for meaningful learning to occur. Mayer and Moreno (2002) report experiments in which learners were presented with animation and narration or animation with both narration and on screen text. In both comparisons, those learners who received material presented in animation and narration performed better on problem-solving transfer tests than those who received animation with both narration and on screen text. The results confirm the redundancy principle, thus supporting the cognitive theory of multimedia learning and conflicting with the learning preferences theory.

Table 1
Instructional Design Principles Derived from the Cognitive Theory of Multimedia Learning

Design Principle	**Description**
Multiple Representation	Present information in both words and pictures
Contiguity	Present corresponding words and pictures simultaneously
Coherence	Eliminate irrelevant information/extraneous words and sounds
Modality	Present words as narration rather than as on screen text
Redundancy	When presenting both pictures and words, the words should be presented as narration only and not as both narration and on screen text

Additional Multimedia Design Considerations: Learner Control and Expertise

Learner control over the pacing of the material being presented in multimedia learning has been identified in the literature as a potential influencing factor on cognitive load and transfer results. However, research regarding the benefits of this control aspect of interactivity has resulted in equivocal results. It appears as though the benefits are dependent on what material is being presented (complexity and element interactivity), to whom the material is being presented (novices or experts), and what type of results are being sought (transfer vs. retention).

Moreno and Mayer (2007) contend that introducing self-pacing reduces cognitive load in working memory by allowing the user to fully process smaller chunks of information at a time before moving on. Mayer and Moreno report studies conducted by Mayer and Chandler (2001) and Mayer, Dow, and Mayer (2003) that each resulted in better transfer test results in those who received segmented, self-paced instruction than those who received continuous instruction. Similarly, Hasler, Kersten, and Sweller (2007) reported results that demonstrated those who were self-paced or segmented in their presentation of the learning material performed better than those who received continuous presentation, particularly on high element interactivity questions.

While Tabbers and de Koeijer (2010) found similar results in that those who had learner control in the presentation of the material to be learned demonstrated better transfer scores than those who did not, they define clear limitations to the use of learner pacing and even report instances in which self-pacing has proved detrimental to learning efficiency. Though the authors found increased transfer performance with learner controlled presentations, this benefit came at the cost of a significant increase in time-on-task, thus compromising efficiency. Further, though transfer scores were improved for those with learner control, there were no differences in retention scores. Tabbers et al. also found individual differences in how the controls were used when available, an occurrence also found in the study conducted by Hasler et al. Hasler et al. found that students who had the option to use pacing controls but chose not to make any or much use of them still performed better than those who did not have a control option, a finding they attributed to the possible greater cognitive investment in the task by those who had the control option. It appears in this case that because they did not have control of the presentation, those who did not have the control option might have let the instruction more passively “happen” to them as it went by without more deeply investing in it. Tabbers et al. empirically investigated this notion in their study and found that learner control did not significantly influence cognitive investment or understanding of the material. Taken as a whole, Tabbers et al. conclude that the benefits of learner control in multimedia learning are gained at the expense of learning efficiency and it remains unclear what individuals would definitively benefit from learner control.

The knowledge level of the learner has also been shown to affect findings relating to the effectiveness of the multimedia design principles. It has been noted previously that as learners become more familiar with a subject, the expertise-reversal effect can occur and presenting information in more than one modality can result in redundancy, thus increasing cognitive load and decreasing the effectiveness of the instruction. Expertise has also been shown to have an influencing effect on the effective use of learner control. Novices, or low knowledge users, tend to misappropriate and mismanage their time when they are in control of the pace. Novices do not have sufficient knowledge to be able to identify the most salient portions of the instruction and they do not effectively monitor control (Betrancourt, 2005; Scheiter & Gerjets, 2007). When learners are able to pace their own learning, the extra time being spent can result in a reversal effect and the benefits of the modality principle are nullified. Considering the effects of pacing and expertise, the modality principle appears to work best for novices and in a learning situation when novices need to learn something more quickly, system-paced animation with narration seems most effective in terms of achieving learning results (Harskamp, Mayer, & Suhre, 2007). If learners are experts or have plenty of time in order to learn the material, the addition of learner control might be beneficial because the learners are able to set their own pace and process all of the information sources individually before integrating them (Mayer & Chandler, 2001).

Empirical Support for the Cognitive Theory of Multimedia Learning

Moreno and Mayer (1999) conducted two experiments aimed at investigating modality and contiguity in multimedia learning. Experiment 1 sought to differentiate between the spatial contiguity and modality effects when learning about the lightning process in a multimedia environment with animation. To accomplish this, the proximity of the written text to the animation and the modality of the verbal information were manipulated. Participants inexperienced in the subject matter were randomly assigned to either a treatment condition instructing with animation and physically close written text, animation and with physically distant written text, or an animation with concurrent auditory text. It was expected that participants in the animation and physically close written text condition would perform better than the animation and physically distant written text condition due to an increase in cognitive load associated with having to integrate distant information sources in the physically distant condition. Further it was expected that those in the animation and auditory text condition would perform better than those in both other conditions due to an increase in effective working memory associated with mixing modalities in the animation and auditory text condition. Participants completed a background questionnaire then experienced instruction in their assigned conditions. Following instruction, participants completed a retention test requiring them to write an explanation of how lightning works and a problem-solving transfer test requiring answers to specific lightning process questions. Finally, participants were presented with a matching test during which frames from the presented animation were to be identified and matched with their descriptions. Results showed the animation with auditory text condition performed significantly higher than both other groups on all three performance tests confirming the modality principle. It was also found that the animation with physically close text performed significantly higher than the animation and physically distant text group on the retention and transfer tests, though no significant difference between these groups was found for the matching test which was attributed to a possible ceiling effect. These results provide evidence for the spatial contiguity principle.

Moreno and Mayer (1999) in experiment 2 sought to differentiate between the temporal contiguity and modality effects when learning about the lightning process in a multimedia environment with animation. It was expected that conditions with auditory text with animations would outperform those with written text and animation. It was also expected that conditions with concurrent presentation would perform better than those with sequential presentation. The procedure for experiment 2 was the same as experiment 1 with the exception of the treatment groups. This experiment used the following conditions: animation with concurrent written text, animation with concurrent auditory text, auditory text followed by animation, animation followed by auditory text, written text preceding animation, and animation followed by written text. The auditory text and animation groups did not differ from each other on verbal recall or problem solving transfer though they each scored significantly higher than the written text and animation groups. Auditory text and animation groups also performed significantly better on verbal matching than the written text and animation groups. These results confirm the modality principle. The experiment failed to confirm a temporal contiguity effect for the auditory text and animation groups, however in the written text with animation groups a significant difference was found such that those receiving concurrent instruction performed worse than those who received sequential instruction. This finding provides evidence for temporal contiguity.

Mayer, Heiser, and Lonn (2001) performed a series of four experiments to investigate the redundancy and coherence effects of the cognitive theory of multimedia learning. Adding redundant written on screen text to accommodate different learning preferences and adding seductive but irrelevant material to bolster interest are two common methods for attempting to improve multimedia presentations of learning material. According to the cognitive theory of multimedia learning however, these techniques actually could have negative effects on learning. In experiment 1, participants were tasked with learning about the formation of lightning and were randomly assigned to either an animation with concurrent auditory text condition, an animation with auditory text along with written text that summarized the concurrent narration with the same words as in the narration condition, an animation with concurrent auditory text with six additional sentences interspersed in the narration that contained interesting but conceptually irrelevant information condition, or an animation with auditory text along with concurrent written on screen text including the same six additional seductive detail sentences. It was expected that, in accordance with the split attention effect of cognitive learning theory, a redundancy effect would be confirmed and those who received on screen text with a narration would perform worse than those who receive auditory text. It was noted that this prediction was only expected when the presentation of the material was done rapidly and the pace could not be controlled by the learner. Participants first completed a questionnaire collecting background information and prior knowledge of the subject and then received their instruction as per their assigned condition. After instruction, a retention test was given asking for a written explanation of how lightning forms and a transfer test was also given requiring answers to specific questions relating to lightning. Consistent with the split attention effect, a redundancy effect was found indicating that the participants receiving written text along with an animation performed significantly worse on both the retention and transfer tests than those who received auditory text and animation. In addition, those receiving additional seductive but irrelevant details performed worse on both the transfer and retention tests indicating a coherence effect.

Experiment 2 in the series done by Mayer, Heiser, and Lonn (2001) sought to investigate whether the redundancy findings of experiment 1 were due to the on screen text creating cognitive load either by competing with the animation in the visual channel for cognitive resources or by demanding resources in the auditory channel to integrate the narration and on screen text. Participants were randomly assigned to either an animation and narration condition, an animation with narration and on screen text that summarized the narration condition, or an animation with narration and on screen text that contained all the exact words of the full narration. It was expected that if the redundancy results of experiment 1 were due to an attempt at integrating an on screen text summary with full narration, the summary text group in experiment 2 would perform most poorly. If the redundancy results were due to competition in the visual channel between text and animation, those receiving no on screen text in experiment 2 should perform better than the other groups. The procedure and tests were the same as in experiment 1. It was found that those receiving no on screen text performed significantly better than the other groups on both the transfer and retention tests. The summary and full text groups did not significantly differ from each other on either test. These findings are reported by the authors as consistent with the split attention effect and provide support for the cognitive theory of multimedia learning which advocates that multiple sources of visual information compete with each other in the visual channel for cognitive resources, thus refuting the information delivery hypothesis stating that information should be presented in more than one way so that learners can choose their preferred source.

Mayer, Heiser, and Lonn’s (2001) third experiment was aimed at investigating the effects of adding seductive details in the form of extra video intended to enhance learner interest and learning. Participants were randomly assigned to conditions in which they received either an animation with narration or an animation with narration along with six videos given at various points in the presentation. Though the videos were relevant to the topic and added interesting details, they were not of relevance to the main concept being taught. It was expected that, consistent with the cognitive theory of multimedia learning and the coherence principle, those receiving the extra seductive videos would perform worse than those who did not receive them. The procedure and tests were the same as in the previous experiments. It was found that the no extra video group did better on the retention test, but the difference was not significant. The no extra video group did significantly better than the extra video group on the transfer test. These results confirm a coherence effect and discredit the idea that adding seductive details improves learning.

Experiment 4 by Mayer, Heiser, and Lonn (2001) sought to further explore the coherence effect (seductive details hypothesis) as opposed to the idea that adding seductive details enhances interest in learning (emotional interest hypothesis). Participants were randomly given a presentation in either an animation with narration and videos after format or a videos prior to animation with narration format. According to the coherence effect, it was expected that when placing videos before the presentation that are irrelevant to the concept to be learned, inappropriate schemas would be triggered prior to instruction which would hinder learning of the target material. The emotional interest hypothesis would suggest that placing the videos before instruction would spark interest in and attention to the topic to be learned. The procedure and tests were the same as the previous experiments. Results indicated that the video after group did better on the retention test than the video before group, but the difference was not significant. The video after group performed significantly better than the video before group on the transfer test. These results are consistent with the coherence effect.

Jamet and le Bohec (2007) conducted an experiment in order to examine the effects of redundancy in multimedia instruction. The experimenters sought to obtain a redundancy effect in addition to determining whether redundancy effects are proportionate to the quantity of the redundant written text presented. It was expected that as written information was presented sequentially in smaller portions at a time rather than cumulatively all at once, the effects of redundancy would be present but diminished due to a reduction of load on the visual channel. In addition, it was predicted that redundancy would have a negative impact on learning retention. The information to be learned was instruction regarding the development of memory models. Participants were randomly assigned to conditions in which they either received timed instruction as a diagram with oral instruction and redundant written information presented in full at once, a diagram with oral instruction and redundant written information presented sequentially, or a diagram with oral instruction only. Participants completed a prior knowledge questionnaire and then were given instruction according to their condition. They were then given a retention test, a transfer test, and a diagram completion test. It was found that the oral instruction condition performed significantly better on all three performance tests than the full text and sequential text conditions. No significant differences were found between the full text and sequential text groups for any performance test. These results supported the redundancy effect hypothesis and confirmed that redundancy has a negative effect on learning. The results did not confirm the hypothesis that the sequential text would significantly reduce the negative effects of redundancy.

Schmidt-Weigand, Kohnert, and Glowalla (2010) studied learner viewing behavior in an attempt to explain the modality and contiguity effects of the cognitive theory of multimedia learning. In observing viewing behavior as a means to witness the learning process, the authors offer a method to discover the way in which learners split their attention and to clarify how split attention factors into explanations of the modality effect. This experiment sought to determine how learners allocate their visual attention under conditions when an animation is given along with written text rather than auditory text and when the written text is spatially manipulated to appear either integrated with the animation or physically separated from the animation. Confirmation of the modality and spatial contiguity effects was expected. Also, it was expected that learners would attend to an animation longer if text was auditory and that they would attend to the animations longer if text was integrated thus reducing visual search time. Further, it was predicted that spatial contiguity and modality effects would relate to how long the learners spent looking at the animations, leading to more visual information being taken in by the learner.

Participants were randomly assigned to experimental conditions in which they received either animations with concurrent auditory text, animations with physically integrated written text, or animations with spatially distant written text. The material to be learned was the formation of lightning. Prior experience information was collected and then the instruction was given in the assigned formats while eye movements were tracked. Following instruction, participants completed a retention test then a transfer test. The group with animation with auditory text only performed significantly better on the transfer and retention test than both other groups demonstrating a modality effect. No significant differences were found between the animation and integrated text and the animation and distant text groups for either transfer or retention, thus failing to support a spatial contiguity effect. The authors caution that this might be due to a small sample size rather than a true lack of the spatial contiguity effect.

With regard to viewing behavior, no significant differences were found between the groups. However *post hoc* comparisons showed that the integrated text group spent significantly more time looking at relevant instruction elements than did those in the auditory text group. It was also found that the auditory text group spent significantly more time viewing the animation than did the other groups. Participants who received written text with animation spent significantly more time reading than they did viewing the animations, there was a negative correlation between reading and viewing animation. No significant difference in reading time was found between the integrated and distant text groups and a marginally significant difference in animation viewing time was found indicating the integrated text group viewed animations longer. It was reported that the integrated text learners spent more time viewing the animations without directing less attention to text. There was a significant correlation between retention and time spent viewing visualizations such that performance increased as viewing time increased. Reading time was not significantly correlated with learning. Viewing behavior revealed that learners who received written text attended to it immediately as it was presented before splitting attention between the text and animation.

Based on the results of the experiment, the authors conclude that learners tended to direct their attention to text and that the success of learning is related to the time spent looking at animations. It was indicated that these conclusions suggests that the way learners process the multimedia material influences learning success. The authors explain the modality and spatial contiguity effects by attributing them in part to learners either missing some visual information on the animation or only superficially processing it when written text is also presented.

Purpose for the Current Study

The current study sought to empirically evaluate the effectiveness of a computer based multimedia simulation tool aimed at teaching immunology to novice students in an instructional setting. An existing simulation was evaluated against alternate configurations including one guided by the theoretical underpinnings provided by cognitive load theory and the cognitive theory of multimedia learning. Of primary interest was which configuration produced significant learning gains and a reduction in mental workload.

Currently, the existing tool provides instruction via animation accompanied by narration and on screen text. Design principles aimed at reducing extraneous load as outlined by cognitive load theory and the cognitive theory of multimedia learning suggest the tool as it currently exists is not optimal for promoting effective learning or reducing cognitive load. Research based in these theories demonstrates that tools developed for novice learners benefit from them more when they adhere to the design principles recommended by the theories. While the current tool is presumed to adhere to the multiple representation, contiguity, and coherence design principles outlined by the cognitive theory of multimedia learning, the currently study sought to apply and test the modality and redundancy principles to determine the most appropriate design for the presentation of the material to reduce mental workload and promote effective learning.

According to the modality principle of the cognitive theory of multimedia learning, when verbal information is to be presented along with an animation in an instructional tool, the verbal material should be presented as narration rather than as on screen text. The application of the modality principle should increase effective working memory capacity thus leaving more resources for processing the information to be learned. By distributing the delivery of information across multiple sensory input channels, overload of any one channel is avoided. Further, the redundancy principle of the cognitive theory of multimedia learning states that an instructional tool that includes an animation and narration should not also include redundant on screen text. Applying the redundancy principle should reduce extraneous processing by freeing cognitive resources through the minimization of unnecessary cognitive activities. By not delivering the same information through any input channel more than once during a presentation, the learner is not required to draw upon cognitive resources to reconcile the redundant information which would leave fewer resources available for information processing. Violating these principles could lead to an increase in cognitive load, thus impeding learning. In evaluating the current multimedia instructional tool, this study assumed acceptance of cognitive load theory and the cognitive theory of multimedia learning and their design principles.

More specifically, in the current study the existing tool consisting of an animation with narration and on screen text was evaluated against an animation and on screen text version as well as the alternate theory driven configuration of animation with narration to determine which version, if any, produced significant learning gains and reduction in mental workload. Mental workload and subject matter knowledge served as the dependent variables to be measured. It was expected that the animation and narration condition would result in lower workload and greater learning performance than all other groups. A modality effect was expected to be observed such that animation with narration would return lower workload and greater learning performance scores than the animation with written on screen text group. A redundancy effect was expected to be found such that the animation and narration group would produce lower workload and better learning performance scores than the animation with narration and written on screen text group.

Research has indicated that self-pacing used in instructional design is done at an overall cost of efficiency and that novices in particular have been shown to misappropriate and mismanage their time when they are in control of the pace of instruction. The tool evaluated in the current study is aimed at producing efficient and effective results in novices and as such was presented for evaluation as a system-paced tool. Because delivery pace has been also demonstrated in the literature to hinder the benefits and observance of the modality and redundancy principles, the pacing speed of the learning material was manipulated and the effects observed. Prior research indicates that when learning material is presented at a slow pace or a pace controlled by the learner, this factor in addition to compromising efficiency can compensate for an increase in imposed cognitive load and can reverse the beneficial learning effects of applying the modality and redundancy principles to instructional design. It was expected that a slow-paced delivery of the learning material would result in the inability to observe the modality and redundancy effects.

CHAPTER 3: METHODOLOGY

Hypotheses

The hypotheses for the current study are driven by cognitive learning theory and the cognitive theory of multimedia learning and are based on the modality and redundancy principles offered in the cognitive theory of multimedia learning.

General Hypotheses

H1: It is hypothesized that the experimental conditions containing animation with narration (A/N) will produce significantly higher learning scores than both the experimental conditions containing animation with on screen text (A/T) and the experimental conditions containing animation with narration and on screen text (A/N/T).

H2: It is hypothesized that the experimental conditions containing animation with narration (A/N) will produce significantly lower workload scores than both the experimental conditions containing animation with on screen text (A/T) and the experimental conditions containing animation with narration and on screen text (A/N/T).

Hypotheses Regarding the Application of the Modality Principle

H3: It is hypothesized that a modality effect will be observed such that the experimental conditions containing animation with narration (A/N) will produce significantly higher learning scores than the experimental conditions containing animation with on screen text (A/T).

H4: It is hypothesized that the experimental conditions containing animation with narration (A/N) will produce significantly lower workload scores than the experimental conditions containing animation with on screen text (A/T).

Hypotheses Regarding the Application of the Redundancy Principle

H5: It is hypothesized that a redundancy effect will be observed such that the experimental conditions containing animation with narration (A/N) will produce significantly higher learning scores than the experimental conditions containing animation with narration and on screen text (A/N/T).

H6: It is hypothesized that the experimental conditions containing animation with narration (A/N) will produce significantly lower workload scores than the experimental conditions containing animation with narration and on screen text (A/N/T).

Hypothesis Regarding Pacing

H7: It is hypothesized that no significant differences in learning or workload will be found between any of the learning conditions receiving instruction at a slow pace. Thus, neither a modality nor redundancy effect is expected to be observed in those learning conditions delivered with a slow pace.

Participants

Two hundred and nineteen participants were recruited from the University of Central Florida, Seminole State College, and Daytona State College via flyers, listservs, word of mouth, and an online participant recruitment site provided by the Institute for Simulation and Training at the University of Central Florida. Data from two participants who reported prior knowledge of cytokine signaling, the immunology topic presented in this experiment, were removed from analysis. The remaining 217 participants (134 women, 83 men, $M_{\text{age}} = 22.44$ years, age range 18-62 years) reported no prior knowledge of cytokine signaling and were retained. Participants received extra course credit or a $10 gift card as compensation for their participation. All participants were required to be at least 18 years of age, to be able to see and hear a projected simulation, and be able to complete paper questionnaires.

Design

A 3 x 3 between-subjects factorial design was used in this study. The independent variables were presentation mode (animation/narration, animation/written text, animation/written text/narration) and pacing speed (fast, medium, slow) and the dependent variables were workload ratings as measured by the NASA-TLX and learning scores as measured by a multiple choice test. Table 2 details each of the 9 experimental groups resulting from the factorial design.

Table 2
Experimental Conditions

	A/N/T	A/N	A/T
Slow Pace	Condition 1	Condition 4	Condition 7
Medium Pace	Condition 2	Condition 5	Condition 8
Fast Pace	Condition 3	Condition 6	Condition 9

Experimental Conditions

Three learning conditions were tested in combination with three pacing conditions resulting in nine experimental conditions. Instruction was presented using either animation with narration (A/N), animation with on screen text (A/T), or animation with narration and on screen text (A/N/T). Instruction was also presented at either a slow pace, a medium pace, or a fast pace. The slow pace consisted of presentation in Flash Player at six frames per second, the medium pace was presented at 12 frames per second, and the fast condition was presented at 19 frames per second.

Software Apparatus

The simulations used in this study were developed in Adobe Flash Professional CS5.5 The simulations consist of animated graphics, recorded voice audio, and text. The animations were presented with Adobe Flash Player 10 on a Windows-based PC. See Appendix E for an example screen capture.

Learning Material

The material presented in the animations, cytokine signaling, is a process typically covered in an immunology course. The graphics used in the animations were modeled from still images commonly used in textbooks for immunology courses. Subject matter expert Dr. Annette Khaled, Associate Professor at the Burnett School of Biomedical Sciences at the University of Central Florida, provided the script from which the on screen text and recorded voice narration were derived.

Assessment Materials

Assessment materials included a demographics questionnaire (Appendix B), a multiple choice subject matter knowledge pre-test (Appendix C), the NASA-Task Load Index (Hart & Staveland, 1988; Appendix D), a multiple choice subject matter knowledge post-test (Appendix F), a subject matter event ordering test (Appendix G), and an opinion survey (Appendix H).

Procedure

Students volunteering to participate in the experiment participated in one of the nine experimental conditions. Because data was collected in group sessions, random assignment of individual participants was not possible. Instead, each of the nine conditions was randomly assigned to a prescheduled data collection session. Participants then scheduled themselves online for a session and received the condition randomly assigned to that session. Upon arrival at a session, participants were given an informed consent form (Appendix A). Following obtaining consent, participants were then asked to complete the demographics questionnaire, the NASA-TLX, and the knowledge pre-test. When all the participants in the group finished these questionnaires, participants then received the instruction according to the assigned condition for the session. Instruction was delivered by projecting the simulation onto a screen that all of the participants watched together at one time. Following instruction, participants were given the NASA-TLX, the knowledge post-test, the event ordering test, and the opinion survey. Participants were then given a post participation sheet containing the contact information of the researcher and committee, thanked, and dismissed. All collected information retained for data analysis was coded numerically for identification purposes. There were no documents retained containing the participants names other than the temporary online appointment log and receipts for distributed gift cards. This information is securely stored separately from all collected data.

CHAPTER 4: RESULTS

Prior to analysis, the data were examined in SPSS for data entry accuracy, outliers, and normality. Variable cell values falling outside three standard deviations of the mean were removed as outliers. Two complete cases were removed due to a significant prior knowledge of cytokine signaling, thus rendering these cases unsuitable for inclusion in this study. Difference scores were computed to be used in the analysis in order to assess changes in learning and workload. Differences scores were created by subtracting the knowledge pre-test score from the knowledge post-test score and subtracting the NASA-TLX pre-test total score from the NASA-TLX post-test total score. A floor effect was observed for the event ordering test and as a consequence, these data were not included in analysis. The data to be used in the analyses were tested for adherence to the assumptions of the ANOVA analysis. All data were found to be within acceptable limits for normality using the skewness and kurtosis statistics and for homogeneity of variance by calculating the $F_{\max}$ values. Because the study is unbalanced, analysis in SPSS with Type III Sums of Squares was elected to adjust for the unequal sample sizes. ANOVA was chosen to examine the effects of each dependent variable rather than MANOVA because of a lack of correlation between the dependent variables.

Workload Results

In order to test hypotheses 2, 4, 6, and 7, NASA-TLX change scores were examined with a 3 (mode) x 3 (pace) analysis of variance (ANOVA). A significant main effect of pace was observed, $F(2, 203) = 6.603$, $p = .002$, $\eta^2 = .05$, such that those in the fast paced conditions demonstrated significantly higher workload scores (*M* = 11.7) than both those in the medium paced conditions (*M* = 8.6) and slow paced conditions (*M* = 8.5). This effect is illustrated in Figure 1. As shown in Figure 2, there was no significant effect of mode, *F*(2, 203) = .884, *p* = .415, η^2 = .007. A significant interaction of mode and pace was observed (Figure 3), *F*(4, 203) = 5.847, $p < .001$, η^2 = .10, such that those who received instruction with animation, narration, and on screen text at a fast pace (*M* = 14.7) exhibited significantly higher workload scores than those who received animation, narration, and on screen text at a slow pace (*M* = 6), those who received animation, narration, and on screen text at a medium pace (*M* = 7.8), and those who received animation and narration at a medium pace (*M* = 8.1). Further, those who received animation and on screen text at a slow pace (*M* = 11.4) showed significantly higher workload scores than those who received animation, narration, and on screen text at a slow pace (*M* = 6). Those receiving instruction with animation and on screen text at a medium pace (*M* = 10.4) demonstrated significantly higher workload scores than those who received animation, narration, and on screen text at a slow pace (*M* = 6). This interaction is depicted in Figure 3. Descriptive statistics for workload difference scores are displayed in Table 3.

Learning Results

In order to test hypotheses 1, 3, 5, and 7, knowledge test change scores were examined with a 3 (mode) x 3 (pace) analysis of variance (ANOVA). As seen in Figures 4 and 5, no significant main effects of mode, *F*(2, 206) = 1.009, *p* = .336, η^2 = .01, or pace, *F*(2, 206) = 1.693, *p* = .187, η^2 = .02, were observed. Further, as illustrated in Figure 6, no significant interaction between mode and pace was found, $F(4, 206) = .613$, $p = .653$, $\eta^2 = .01$. Descriptive statistics for knowledge difference scores are displayed in Table 4.

In order to fulfill a request made by the committee of this dissertation, an additional analysis was conducted to investigate the overall learning effects of exposure to the tool regardless of the mode or pace of the presentation. A paired samples t-test was conducted to compare knowledge test scores from pre-test to post-test. A significant difference was observed such that knowledge post-test scores ($M = 5$) were significantly greater than knowledge pre-test scores ($M = 3.1$); $t(216) = -15.04$, $p < .001$, $\eta^2 = .51$.

Table 3
Descriptive Statistics for Workload Difference Scores

Mode	**Pace**	**Mean**	**SD**	**N**
A/N/T	Slow	6.0	4.7	27
	Medium	7.8	3.1	30
	Fast	14.7	3.7	9
A/N	Slow	8.5	4.9	29
	Medium	8.1	4.6	38
	Fast	11.3	3.8	12
A/T	Slow	11.4	3.4	25
	Medium	10.4	3.7	34
	Fast	9.1	3.4	8
Total	Slow	8.5	4.9	81
	Medium	8.8	4.0	102
	Fast	11.7	4.2	29
	Total	9.1	4.5	212

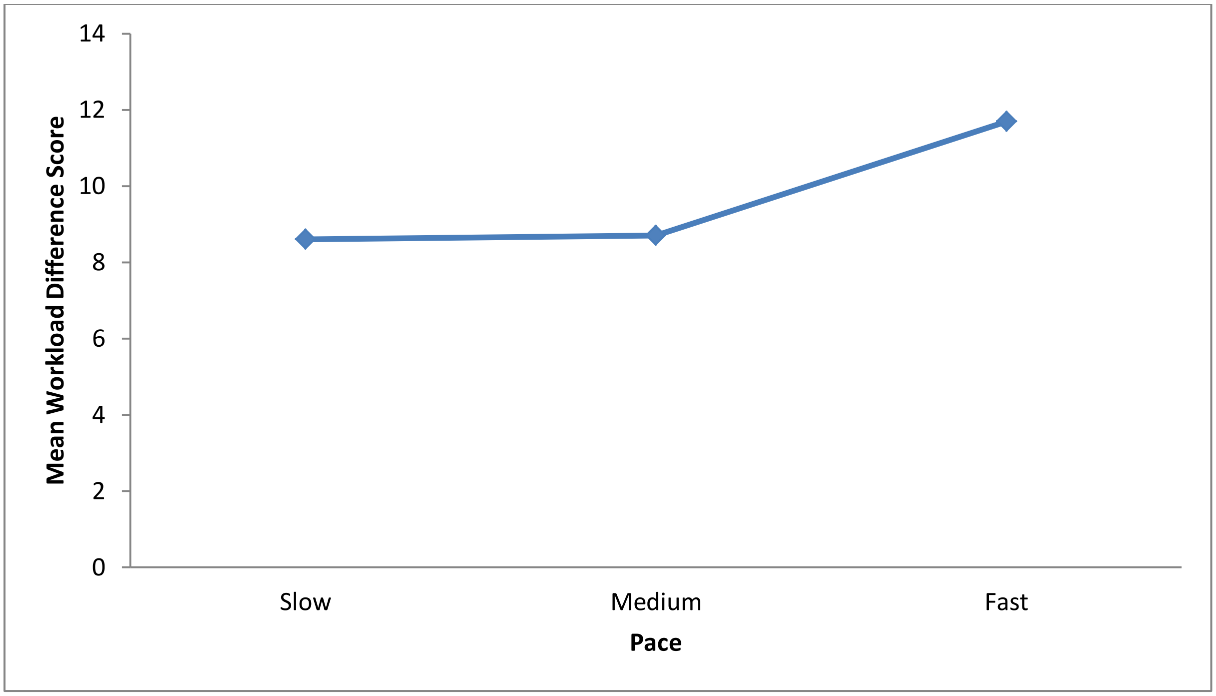

Figure 1. Mean Workload Difference Scores by Instructional Pace

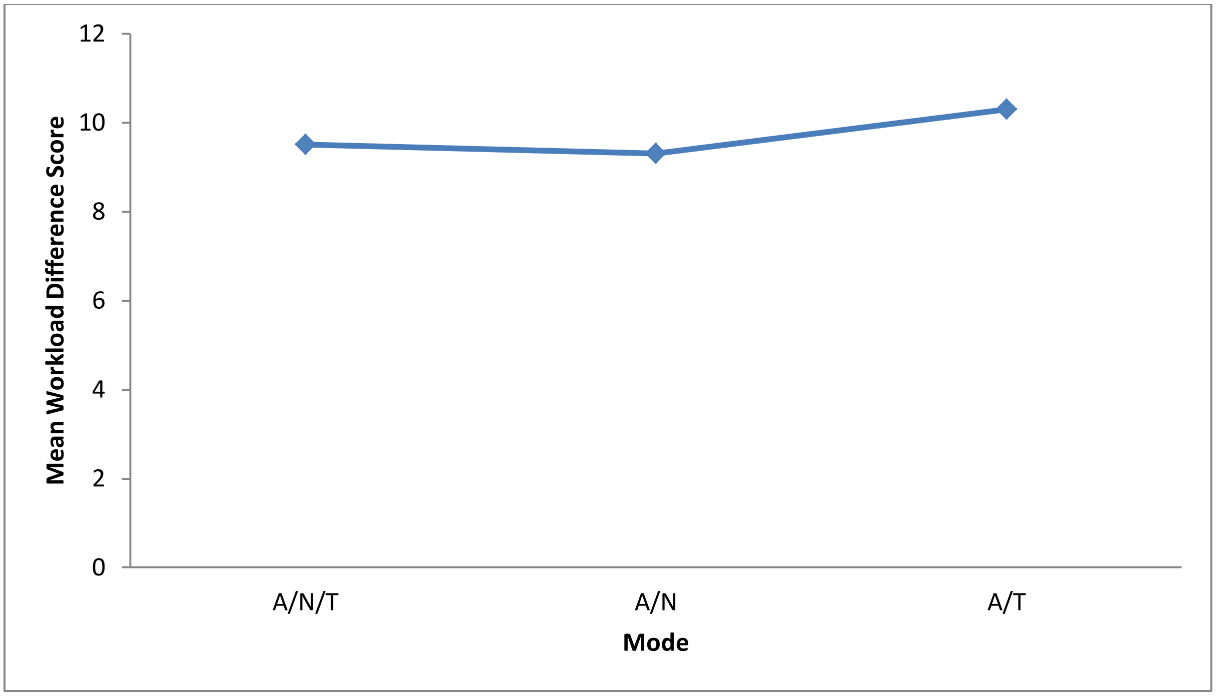

Figure 2. Mean Workload Difference Scores by Instructional Mode

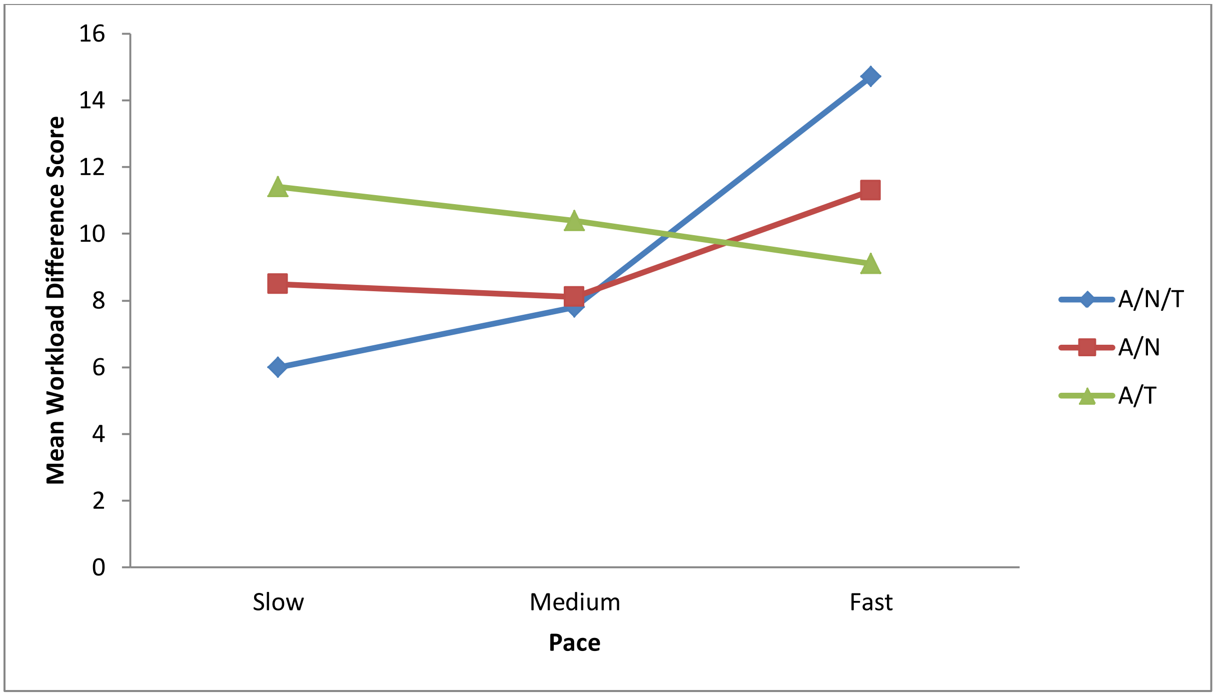

Figure 3. Mean Workload Difference Scores: Instructional Pace by Mode

Table 4
Descriptive Statistics for Knowledge Change Scores

Mode	**Pace**	**Mean**	**SD**	**N**
A/N/T	Slow	2.3	1.7	28
	Medium	2.5	1.8	30
	Fast	1.4	1.9	9
A/N	Slow	2.0	1.6	29
	Medium	1.8	2.2	39
	Fast	1.1	1.9	11
A/T	Slow	2.3	1.8	26
	Medium	1.7	1.7	35
	Fast	1.9	.6	8
Total	Slow	2.2	1.7	83
	Medium	2.0	1.9	104
	Fast	1.4	1.6	28
	Total	2.0	1.8	215

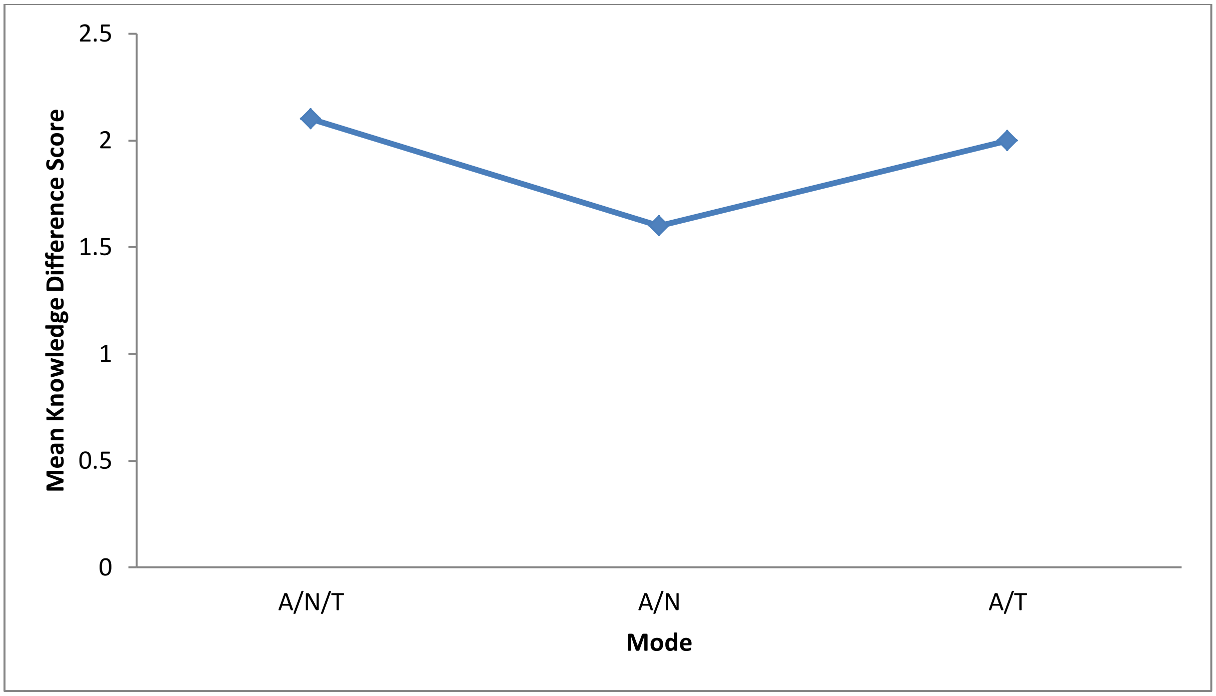

Figure 4. Mean Knowledge Difference Scores by Instructional Mode

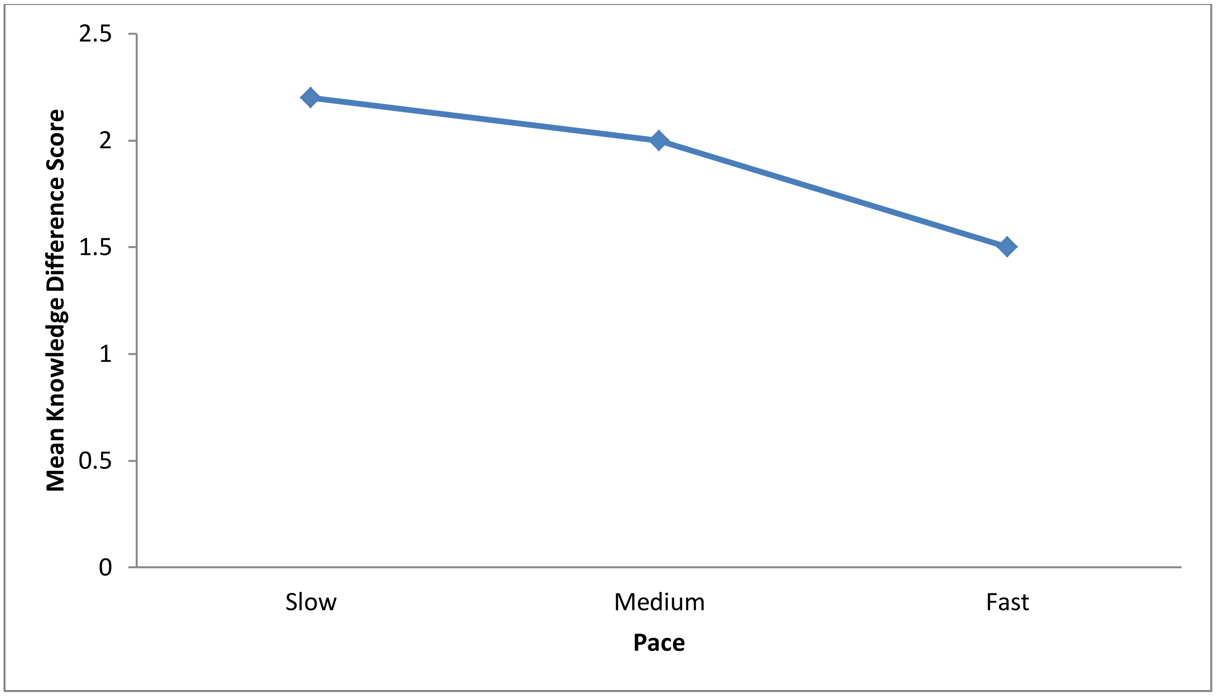

Figure 5. Mean Knowledge Difference Scores by Instructional Pace

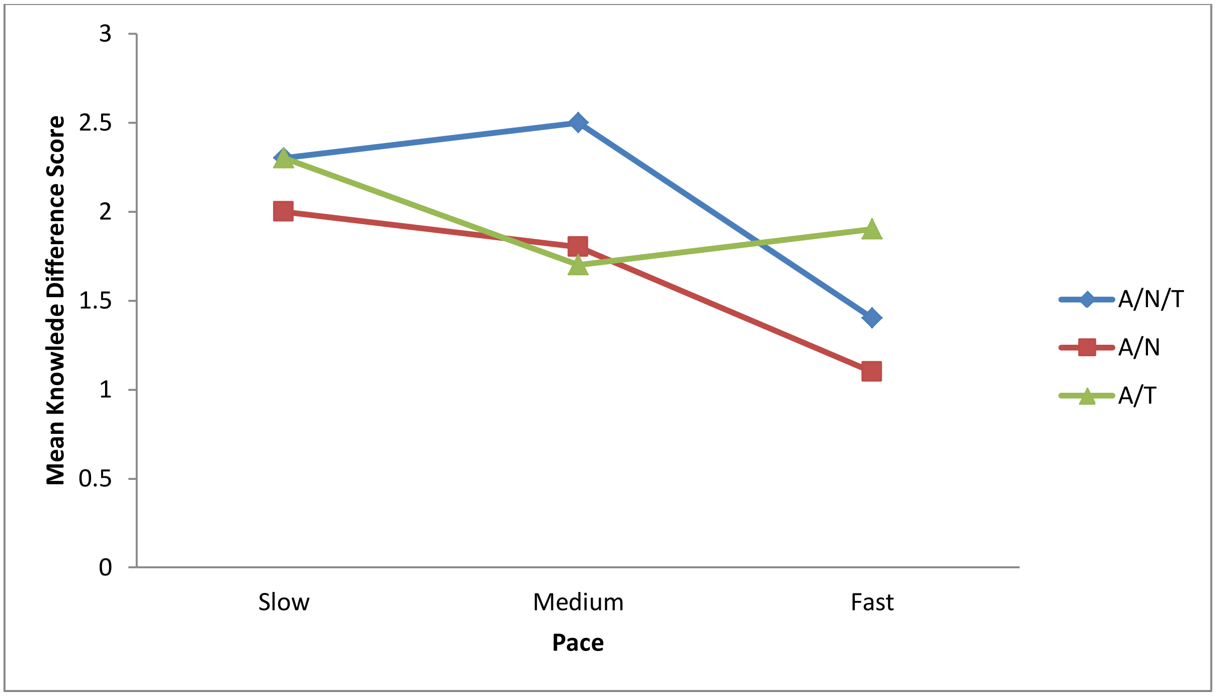

Figure 6. Mean Knowledge Difference Scores: Instructional Pace by Mode

CHAPTER 5: DISCUSSION

The objective of this study was to evaluate the effectiveness of a computer based multimedia simulation tool developed for teaching immunology to novice students in an instructional setting. An existing simulation was evaluated against alternate configurations and the hypotheses were guided by the theoretical underpinnings provided by cognitive load theory and the cognitive theory of multimedia learning. Of primary interest was which configuration produced significant learning gains and a reduction in mental workload relative to the other configurations.

The tool as it was originally designed provides instruction via animation accompanied by both narration and on screen text. Design principles aimed at reducing extraneous load as outlined by cognitive load theory and the cognitive theory of multimedia learning suggest this might not be the most optimal configuration for promoting effective learning or reducing cognitive workload. Research based in these theories demonstrates that tools developed for novice learners benefit more from them when they follow the design principles recommended by the theories. As such, it was hypothesized that the tool in a configuration that adhered to the modality and redundancy principles would ultimately return greater learning gains and reductions in workload than those not adhering to the principles. However, the results of this study failed to support any of the hypotheses based on the design principles offered by cognitive load theory and the cognitive theory of multimedia learning. Neither a modality effect nor a redundancy effect was found and no significant learning gains were observed between any of the configurations of the learning tool regardless of mode or pace. Workload was found to be influenced by pace alone as well as an interaction between mode and pace, however the observed relationship was not as predicted in the hypotheses.

Although the results of this study failed to directly support cognitive load theory and the cognitive theory of multimedia learning through successful application of the design principles, one could look to these same theories for a potential explanation for why the expected results were not found in this instance. It is quite possible that the learning material presented with the tool was too high in intrinsic cognitive load to observe any benefits of applying techniques to reduce extraneous load. Recall that intrinsic load refers to the complexity of the material to be learned and the working memory demand imposed by this complexity is intrinsic to the material to be learned (Paas, Renkl, & Sweller, 2003). As noted, the relationship between the three types of cognitive load is additive, though unequal, to result in overall cognitive load. The base load is provided by intrinsic load which is not reducible, except in cases where schemas are constructed and automation of previous schema occurs thus changing the level of learner experience or expertise (Paas, Renkl, et al., 2003). After the intrinsic load is established and available cognitive resources are allocated to it, the remainder of the available cognitive resources are directed to extraneous and germane load. Extraneous and germane load can have a reciprocal relationship, when one load is reduced, it leaves more cognitive resources for the other (Paas, Renkl, et al., 2003). High intrinsic load as indicated by high element interactivity and low learner experience and insufficient schemata, however, can leave few resources to be allocated to extraneous and germane load (Bannert, 2002). The goal of instructional design according to cognitive load theory is to make use of germane cognitive load to foster learning while reducing extraneous load and managing intrinsic cognitive load to leave sufficient working memory capacity for learning (Clark et al, 2006). Total cognitive load in an instructional design should not exceed working memory capacity in order for efficient learning to occur (Kalyuga, 2007; Paas, Renkl et al., 2003; Paas, Tuovinen, et al., 2003). In the case of the tool evaluated in this study, the intrinsic load was likely too high and the experience level of the learner too low for the benefits of applying the design principles to reduce extraneous load to make any significant impact. The working memory of the learners was likely taxed too closely to capacity for learning to occur.

The results in this study did not support the hypothesized relationship of pace and mode with workload as was expected from the application of the design principles. The pattern of the actual findings is inconsistent and at first glance the interpretation is ambiguous. However, the findings if viewed in the context of the learners being at maximum capacity might instead provide insight into the learners’ stress adaptability levels under maximum capacity. Hancock and Warm (1989) propose a dynamic model of stress in which a normative zone is surrounded by a comfort zone. It is within this comfort zone that an individual is believed to perform at a normal target value. Outside the comfort zone are regions of hypo or hyperstress which indicate that a certain degree of stress or arousal is needed to operate within the normative. When stress reaches either the hypo or hyperstress bounds, the psychological maximal adaptibilty zone is pressed to its limit and eventually declines rapidly to minimal adaptability. The failure point in this model for physiological maximal adaptability occurs further into hypo or hyperstress but represents a more serious danger. Performance decrements are thought to occur as stress levels move toward hypo or hyperstress and these decrements are likely a result of the individual’s inability to return to a normal state due to the costliness of the resources employed to remedy the problem. This model perhaps explains the workload results observed in this study. As discussed, no learning gains were found for any of the groups in this study. Assuming that intrinsic load was too high and the learners were all at or near maximum capacity in working memory, one would not expect to see significant learning differences across groups. Further, workload ratings would be expected to be high but relatively equal across groups assuming the learners in all conditions were sustaining performance within the bounds of the adaptability region that precedes a performance breakdown in the hyperstress region. For some conditions in this study, significant differences were found in perceived workload ratings based on the mode and pace of the instruction. Interpreting these differences in the context of the dynamic stress model offered by Hancock and Warm, it would appear that the points where significant differences in workload were observed represent the failure points at which the learners in a particular group exceeded maximal adaptability and progressed into hyperstress relative to other groups still remaining within adaptability bounds. This provides insight into the learning conditions under which a learner is pushed beyond adaptability, for this study the observable breakdown occurred most often for learners that received all three presentation modes at a fast pace.

Limitations

There are several limitations to consider before drawing conclusions based upon the results of this study. The learning tool presented in this study was done so in isolation, it was presented as the sole information source from which to learn the material. Further, the material being presented in the instruction is high in complex terminology and this in turn increases the intrinsic load of the material. Under conditions of high intrinsic load and low learner experience such as in this experiment, support from the instructional design is not likely to impact learning.

Learners in instances such as this would need to build base schema prior to receiving the learning tool to compensate for the intrinsic load imposed by the material. As such, introducing the terminology in some form of lecture or alternate instruction prior to delivering the simulation might have been beneficial. This type of pairing between an introductory reading assignment or lecture and the subsequent presentation of the simulation as a support tool to enhance visualization of the material is also a closer representation of the likely application of the tool. In addition, this study did not investigate the relative effectiveness of presenting images with animation or in still diagrams.

Recommendations and Future Research

Because the primary focus of this study was to evaluate different configurations of the tool to determine which was more effective relative to other configurations, the results of this study based on the hypotheses do not provide information regarding the overall effectiveness of general exposure to the tool regardless of presentation mode or pace. As such, the analysis requested by the dissertation committee was designed to investigate this alternate global perspective. The results of this additional analysis illustrate an important finding regarding the potential value of the tool and also warrant further development and continuing research of this tool as a learning device. Although significant differences in learning were not found between the experimental groups as a result of manipulating the mode or pace of presentation, significant learning gains were found as a result of general exposure to the tool regardless of presentation configuration. This finding indicates that participants were able to learn the material to some degree as a result of being exposed to the tool in general. This result alone is promising and illustrates the potential of this tool as an effective learning device, particularly when considering the tool was presented only once and also in isolation. Additionally, this finding provides some evidence for the potential effective use of multimedia animations for presenting learning material of this type.

Based on the results of this study, it is recommended that further investigation be done with regard to the use of the tool as a *support* tool used in conjunction with a lecture or prior instruction to build schema and reduce intrinsic cognitive load. A review of the free responses provided by the participants in the study provide some additional support for the argument that intrinsic load was too high for the tool to be effective without an accompanying lecture or alternate pre-exposure to the material to be learned. Many of the participants when asked to describe any feelings they had regarding the simulation and their related learning experience responded that they felt they needed to see the simulation more than once to grasp the terminology before attempting to visualize the process or expressed a desire to receive an introduction to the material and associated terminology prior to viewing the simulation. Further investigation into the design principles and their possible exceptions is also merited based on these results. When complex terminology is to be presented in a multimedia tool, this might present a condition under which the modality principle would not apply and on screen text would be helpful rather than a hindrance.

Although not formally included in the analysis, the results of a subjective opinion survey provide some evidence for the preference of simulations as learning tools over textbook images and lessons. Sixty percent of the participants in this study indicated a general preference for learning with a simulation as compared to a traditional lecture or textbook lesson. Eighty one percent felt the simulation presented in this study was an effective teaching tool. Seventy six percent felt that being presented with the learning material in this study through a simulation made it easier to learn than if presented only in a lecture or textbook. Eighty two percent felt that learning this material through a simulation was more enjoyable than if they were learning it from a lecture or textbook only. Seventy three percent felt the simulation helped them visualize the cytokine signaling process. These results warrant further objective investigation into individual differences and preferences for simulation as they relate to the effective use of simulation for material of this type.

APPENDIX A: INFORMED CONSENT

The effects of presentation mode on learning immunology with computer simulation: A cognitive evaluation of a multimedia learning resource.

Informed Consent

Principal Investigator(s):	Kristy A Bradley, M.S.
Faculty Supervisor:	J. Peter Kincaid, Ph.D.
Investigational Site(s):	UCF Institute for Simulation and Training, Seminole State College (SSC), and Daytona State College (DSC)

Introduction:

Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 252 people from UCF, DSC, or SSC. You have been asked to take part in this research study because you are a student at UCF, DSC, or SSC. You must be 18 years of age or older to be included in the research study and you must be able to see and hear a projected simulation on a screen. You must also be able to read instructions on paper questionnaires.

The person doing this research is Kristy A. Bradley, a doctoral student in the Modeling and Simulation program at UCF and the Institute for Simulation and Training (IST). Because the researcher is a graduate student, she is being guided by Peter Kincaid, Ph. D., a UCF faculty supervisor in Modeling and Simulation.

What you should know about a research study:

- Someone will explain this research study to you.
- A research study is something you volunteer for.

- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study:

The purpose of this study is to examine the benefits of using multimedia computer simulation on learning immunology processes.

What you will be asked to do in the study:

Once you arrive to participate in the study, you will be asked to complete a demographics questionnaire, a questionnaire relating to the material to be presented in the simulation, and a questionnaire about your mental workload. After these questionnaires, you will watch a computer simulation of an immunological process. After you finish watching the simulation, you will again be asked to answer questions about the simulation and your mental workload. You do not have to answer every question or complete every task. You will not lose any benefits if you skip questions or tasks. You will only be asked to make 1 visit to participate in this study.

Location:

Institute for Simulation and Training, UCF Partnership II Building, Room 206, 3100 Technology Pkwy in Research Park; Seminole State College Oviedo and Altamonte Campuses; Daytona State College South Campus

Time required:

We expect that you will be in this research study for approximately 45 minutes, no more than 1 hour.

Risks:

There are no reasonably foreseeable risks or discomforts as a result of participation in this study.

Benefits:

We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include knowledge of the research process and knowledge of the immunological process presented in the study.

Compensation or payment:

You may choose to receive extra credit <u>or</u> a $10 gift card as compensation for your participation. Please be aware that the acceptance of extra credit is done at the discretion of your instructor. If you choose not to participate, you may notify your instructor and ask for an alternative assignment of equal effort for equal credit. There will be no penalty.

Confidentiality:

We will limit your personal data collected in this study to people who have a need to review this information. We cannot promise complete secrecy. However, all the information you provide throughout participation in this study will be stored in such a way that it will not be connected to your name in any way. Also, all experimental data we collect will be stored in such a way that there will be no way of linking your name to your data file(s).

Anonymous research:

This study is anonymous. That means that no one, not even members of the research team, will know that the information you gave came from you. Your name will not be linked to any data that is collected.

Study contact for questions about the study or to report a problem:

If you have questions, concerns, or complaints, or think the research has hurt you, please contact any of the following:

Kristy A. Bradley, M.S.
University of Central Florida
Institute for Simulation and Training
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Peter Kincaid, Ph.D.
University of Central Florida
Institute for Simulation and Training
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Adams Greenwood-Ericksen, Ph.D.
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Game Studies Department
Phone: (407) 679-0100 ext. 8912
Email: agreenwoodericksen@fullsail.com

IRB contact about your rights in the study or to report a complaint:

Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

APPENDIX B: DEMOGRAPHICS QUESTIONNAIRE

Please answer the following questions:

1. What is your age in years: ____

2. Please circle your gender: Female Male

3. What is your major (if applicable)?____

4. What is your profession (if applicable)? ____

5. What is the highest degree you have obtained? Circle one:

Some High School	High School Diploma	Some College
Bachelor's Degree	Some Graduate School	Graduate Degree

6. What is your primary language? _______________

7. Do you require corrected vision? Yes No

   If yes, do you wear glasses? Yes No

   If you wear glasses, are you wearing them right now for this experiment? Yes No

   If yes, do you wear contact lenses? Yes No

   If you wear contact lenses, are you wearing them right now for this experiment?

   Yes No

8. Have you ever studied or worked in biomedical sciences/immunology? Yes No

   If yes, please describe your experience:

   ____

   ____

9. How would you describe your degree of knowledge of biomedical sciences/immunological processes? Circle one:

   Poor Fair Average Above average Proficient

10. Do you have any knowledge of cytokine signaling? Yes No

If yes, please describe cytokine signaling: ____

____

____

11. Do you use computers for leisure? Yes No

If yes, please estimate the number of hours you use a computer for leisure per week: ____

12. Do you use computers for work? Yes No

If yes, please estimate the number of hours you use a computer for work per week: _____

13. Do you use computers for study?: Yes No

If yes, please estimate the number of hours you use a computer for study per week: _____

14. How would you describe your degree of comfort with computers? Circle one:

Poor Fair Average Above average Proficient

APPENDIX C: KNOWLEDGE PRE-TEST

Please circle the correct choice:

1. Cells of the innate and adaptive immune systems secrete ______________.
   a) serotonin
   b) rhodopsin
   c) pepsinogen
   d) cytokines

2. Cytokine receptors engage signal transduction pathways through activation of ____________ called Janus kinases, or JAK.
   a) neurotransmitters
   b) enzymes
   c) photoreceptors
   d) steroids

3. Prior to cytokine binding, inactive JAK enzymes are non-covalently attached to the ________________ domain of cytokine receptors.
   a) cytoplasmic
   b) external
   c) presynaptic
   d) nuclear

4. As a result of dimerization, receptor associated JAK enzymes become activated through the process of ________________.
   a) summation
   b) transphosphorylation
   c) exocytosis
   d) depolarization

5. The phosphorylated tyrosine residues are recognized by the ___________ domains of the STAT proteins.
   a) NT5
   b) SH2
   c) PP1
   d) GH2

6. STAT proteins attach to the cytokine receptors and are in turn phosphorylated by the receptor-associated ___________ enzymes.
    a) STAT
    b) JAK
    c) SH1
    d) LAK

7. The STAT dimer migrates to the _________________.
    a) nucleus
    b) cytoplasm
    c) synapse
    d) receptor

8. STAT dimer binding activates ________________.
    a) cell division
    b) neurotransmitter receptors
    c) protein denaturation
    d) gene transcription

APPENDIX D: NASA-TLX

Workload Rating Instructions

Part I

Rating Scales. We are not only interested in assessing your performance but also the experiences you had during the experiment. In the most general sense, we are examining the "workload" you experienced. Workload is a difficult concept to define precisely but a simple one to understand generally. The factors that influence your experience of workload may come from the task itself, your feelings about your own performance, how much effort you put into it, or the stress and frustration you felt. In addition, the workload contributed by different task elements may change as you become more familiar with the task. Physical components of workload are relatively easy to conceptualize and evaluate. However, the mental components of workload may be more difficult to assess.

Since workload is something that is experienced individually by each person, there are no set "rulers" that can be used to estimate the workload associated with different activities. One way to find out about workload is to ask people to describe the feelings they experienced while performing a task. Because workload may be caused by different factors, we would like you to evaluate several of them individually rather than by lumping them into a single, global evaluation of overall workload. This set of six rating scales was developed for you to use in evaluating your experiences during this task. Please read the descriptions of the scales carefully. If you have any questions about any of the scales in the table, please ask me about them. It is extremely important that they be clear to you. You may keep the descriptions with you for reference while completing the scales.

For each of the six scales, you will evaluate the task by circling a point on the scale to reflect the point that matches your experience. Pay close attention to each scale's endpoint description when making your assessments. Note that when the rating scale for PERFORMANCE appears, the scale will go from "good" on the *left* to "poor" on the *right*. This means that a *low* number will represent good performance, while a *high* number will signify poor performance. This order has been confusing for some people. Please read the description for each scale again before making your rating.

1. Mental Demand How mentally demanding was the task?

|___|___|___|___|___|___|___|___|___|___ | ___|

Workload Rating Instructions
Part II

Pairwise Comparisons. Rating scales of this sort are extremely useful, but their utility is diminished by the tendency people have to interpret them in different ways. For example, some people feel that mental or temporal demands are the greatest contributors to workload regardless of the effort they expended in performing a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low; and if they performed poorly, then it must have been high. Still others believe that effort or feelings of frustration are the most important determinants of their experiences of workload. Previous studies using this scale have found several different patterns of results. In addition, the factors that determine workload differ depending on the task. For instance, some tasks might be difficult because they must be completed very quickly. Other tasks may seem easy or hard because the degree of mental or physical effort required. Some task may seem difficult because they cannot be performed well no matter how much effort is expended.

The next step in your evaluation is to assess the relative importance of the six factors in determining how much workload you experienced. You will be presented with pairs of rating scale titles (e.g. EFFORT vs. MENTAL DEMAND) and asked to choose which of the two items was more important to your experience of workload in the task that you just performed.

Please consider your choices carefully and try to make them consistent with your scale ratings. Refer back to the rating scale definitions if you need to as you proceed. There is no correct pattern of responses. We are only interested in your opinions.

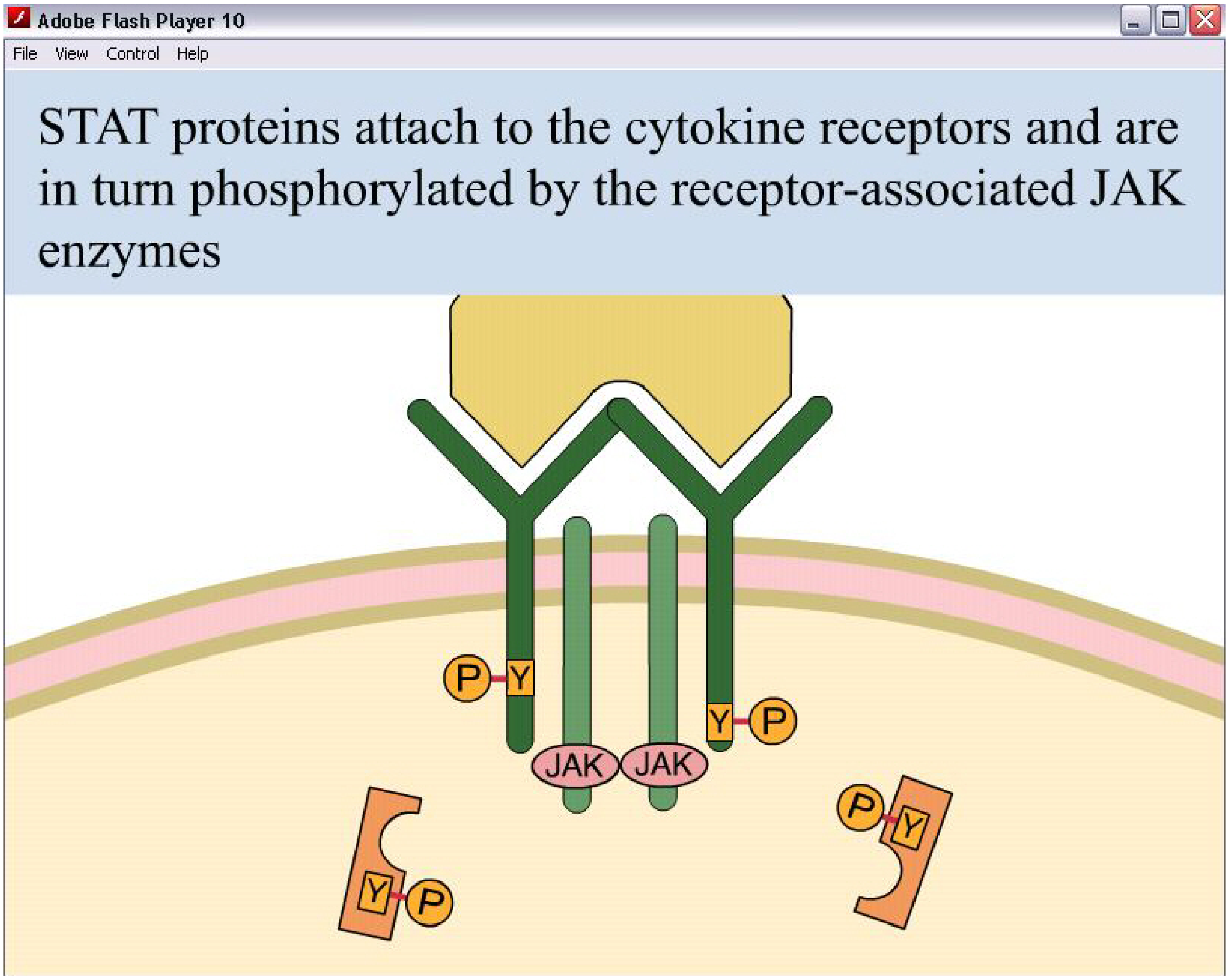
Please circle the more important contributor to workload in each comparison:

1. Frustration or Mental Demand
2. Mental Demand or Temporal Demand
3. Performance or Effort
4. Frustration or Temporal Demand
5. Effort or Frustration
6. Performance or Mental Demand
7. Physical Demand or Performance
8. Temporal Demand or Physical Demand
9. Effort or Temporal Demand
10. Performance or Frustration
11. Physical Demand or Mental Demand
12. Effort or Physical Demand
13. Mental Demand or Effort
14. Temporal Demand or Performance
15. Physical Demand or Frustration

RATING SCALE DEFINITIONS

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	LOW/HIGH	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	LOW/HIGH	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	LOW/HIGH	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	GOOD/POOR	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	LOW/HIGH	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	LOW/HIGH	How insecure, discouraged, irritated stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

APPENDIX E: SIMULATION SCREEN CAPTURE



STAT proteins attach to the cytokine receptors and are in turn phosphorylated by the receptor-associated JAK enzymes

APPENDIX F: KNOWLEDGE POST TEST

Please circle the correct choice:

1. Cytokines are secreted by cells of the innate and adaptive ____________ systems.
   e) musculoskeletal
   f) epidermal
   g) immune
   h) nervous

2. Cytokines are produced in response to ______________ in order to stimulate diverse cell responses.
   i) microbes
   j) neuron transmission
   k) hypoxia
   l) lipid metabolism

3. JAKs in turn activate a family of _________________ called signal transducers and activators of transcription, or STATs.
   m) hormone inhibitors
   n) thermoreceptors
   o) transcription factors
   p) chemoreceptors

4. Two cytokine receptor molecules are brought together by ____________ a cytokine molecule.
   q) severing
   r) metabolizing
   s) removing
   t) binding

5. Active JAK enzymes then _____________ key residues in the cytoplasmic portion of the cytokine receptors.
   u) phosphorylate
   v) acetylate
   w) oxidize
   x) methylate

6. STAT proteins link cytokine binding to the activation of target ________________.
    y) LCAM-1
    z) blood cells
    aa) hormones
    bb) genes

7. The SH2 domain of one STAT protein is able to bind to the phosphorylated __________________ on another STAT protein.
    cc) tyrosine
    dd) lysine
    ee) glycine
    ff) threonine

8. The STAT dimer binds to the _______________ of a cytokine responsive gene
    gg) chemical receptor region
    hh) immunoreceptor region
    ii) promoter region
    jj) inhibitor region

APPENDIX G: ORDERING TEST

Please place the following events as they were presented in the simulation in order from beginning to end. Begin numbering the events with 1.

_______ Prior to cytokine binding, inactive JAK enzymes are non-covalently attached to the cytoplasmic domain of cytokine receptors

_______ The STAT proteins disassociate from the cytokine receptor and form a STAT dimer.

_______ As a result of dimerization, receptor associated JAK enzymes become activated through the process of transphosphorylation

_______ Two cytokine receptor molecules are brought together by binding a cytokine molecule

_______ The STAT dimer activates gene transcription

_______ The SH2 domain of one STAT protein is able to bind to the phosphorylated tyrosine on another STAT protein.

_______ Cytokines are secreted by the cells of the innate and adaptive immune systems

_______ The STAT dimer migrates to the nucleus where it binds to the promoter region of a cytokine responsive gene

_______ Active JAK enzymes then phosphorylate key residues in the cytoplasmic portion of the cytokine receptors

_______ Cytokines are produced in response to microbes and other antigens in order to stimulate diverse cell responses

_______ The phosphorylated tyrosine residues are recognized by the SH2 domains of the STAT proteins

_______ STAT proteins attach to the cytokine receptors and are in turn phosphorylated by the receptor-associated JAK enzymes.

APPENDIX H: OPINION SURVEY

Please answer the following questions:

1. Do you feel that you learned the material that was presented to you?
   a. yes
   b. no

2. Please indicate on the scale below how well you feel you learned the material presented.

1---------------------2---------------------3---------------------4---------------------5

Not at all	A little	Reasonably well	Well	Very well

3. Do you feel that the simulation you viewed helped you visualize and understand the cytokine signaling process?
   a. yes
   b. no

4. Do you feel that learning this material through simulation was more enjoyable than if it was presented only in a lecture or in a textbook?
   a. yes
   b. no

5. Do you feel that being presented with this material through simulation made it easier to learn than if it was presented only in a lecture or textbook?
   a. yes
   b. no

6. Do you feel that the simulation you viewed is an effective teaching tool?
   a. yes
   b. no

7. Please indicate on the scale below how effective you feel the simulation you viewed is as a teaching tool.

1---------------------2---------------------3---------------------4---------------------5

Not at all effective	A little effective	Reasonably effective	Effective effective	Very effective

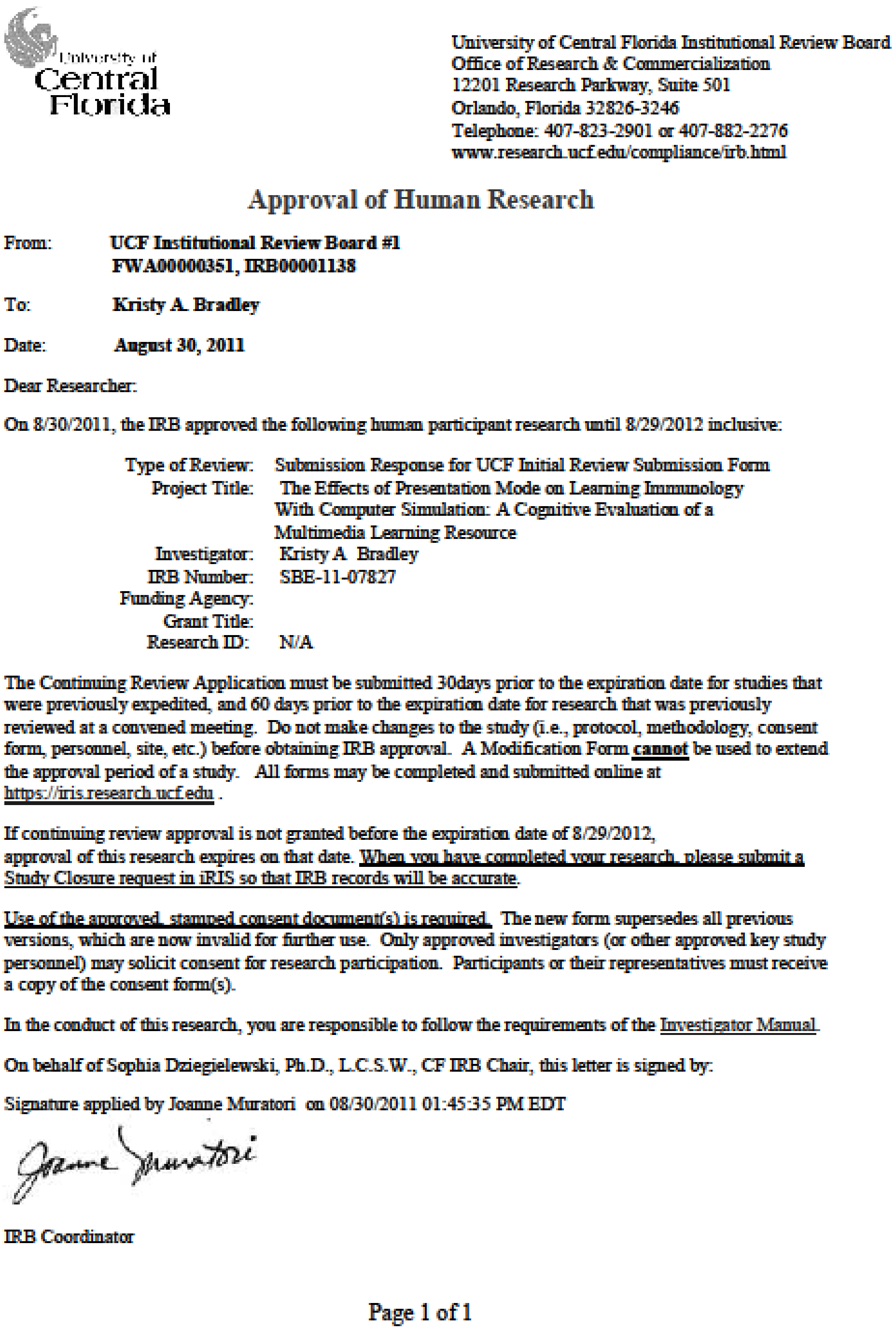
8. Please indicate on the scale below your preference for learning through simulation in general as compared to traditional lecture or textbook methods.

1---------------------2---------------------3---------------------4---------------------5
Do not prefer   Sometimes prefer   No preference   Prefer   Always prefer

9. Please describe any feelings/comments you have about your experience on learning from the simulation you viewed.

10. Please describe any feelings/comments you have about the simulation you viewed.

APPENDIX I: IRB APPROVAL LETTERS



University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
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Orlando, Florida 32826-3246
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www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Kristy A. Bradley**

Date: **August 30, 2011**

Dear Researcher:

On 8/30/2011, the IRB approved the following human participant research until 8/29/2012 inclusive:

Type of Review:	Submission Response for UCF Initial Review Submission Form
Project Title:	The Effects of Presentation Mode on Learning Immunology With Computer Simulation: A Cognitive Evaluation of a Multimedia Learning Resource
Investigator:	Kristy A Bradley
IRB Number:	SBE-11-07827
Funding Agency:	
Grant Title:	
Research ID:	N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 8/29/2012, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., CF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 08/30/2011 01:45:35 PM EDT

Joanne Muratori

IRB Coordinator

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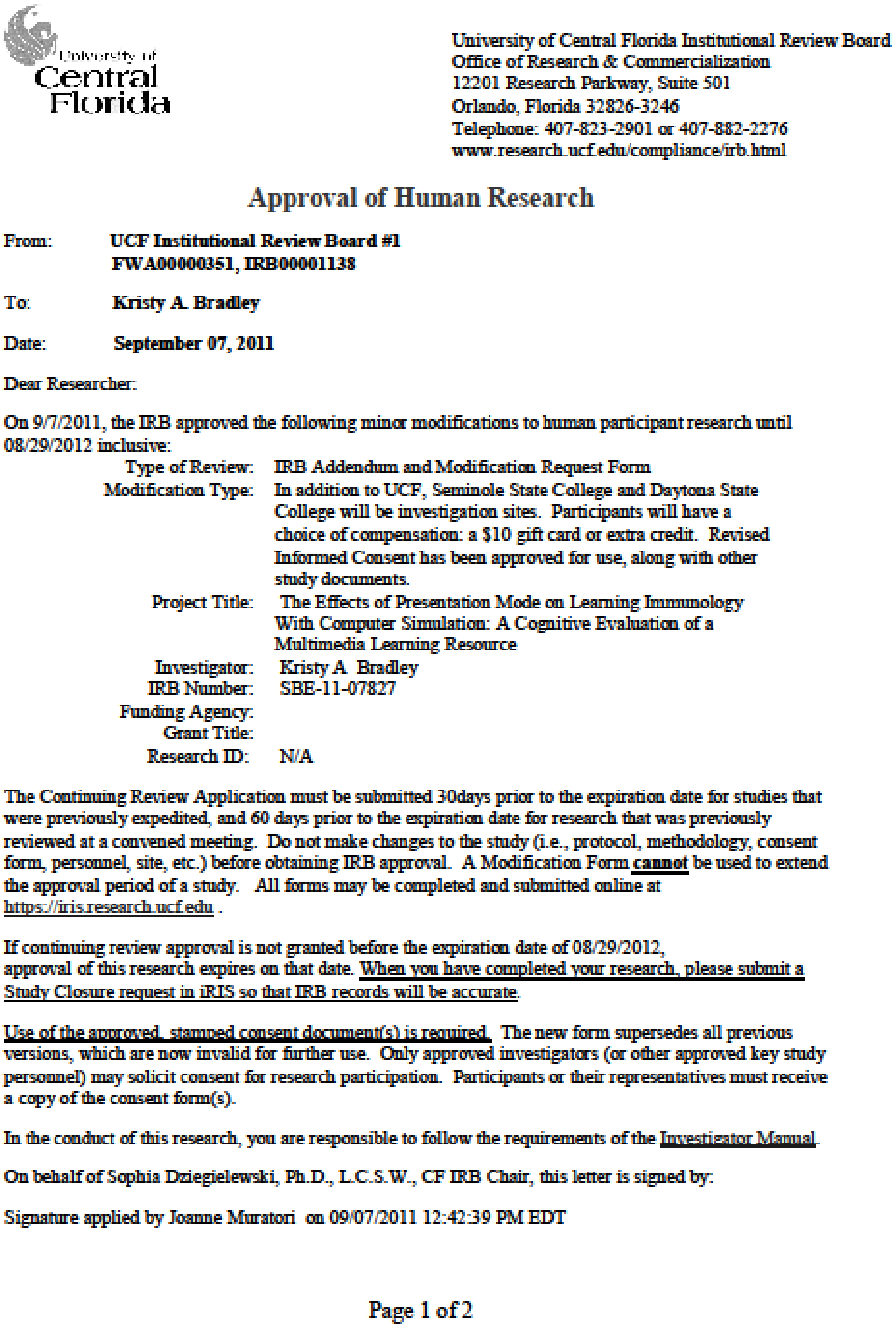

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Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Kristy A. Bradley**

Date: **September 07, 2011**

Dear Researcher:

On 9/7/2011, the IRB approved the following minor modifications to human participant research until 08/29/2012 inclusive:

Type of Review:	IRB Addendum and Modification Request Form
Modification Type:	In addition to UCF, Seminole State College and Daytona State College will be investigation sites. Participants will have a choice of compensation: a $10 gift card or extra credit. Revised Informed Consent has been approved for use, along with other study documents.
Project Title:	The Effects of Presentation Mode on Learning Immunology With Computer Simulation: A Cognitive Evaluation of a Multimedia Learning Resource
Investigator:	Kristy A Bradley
IRB Number:	SBE-11-07827
Funding Agency:	
Grant Title:	
Research ID:	N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 08/29/2012, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

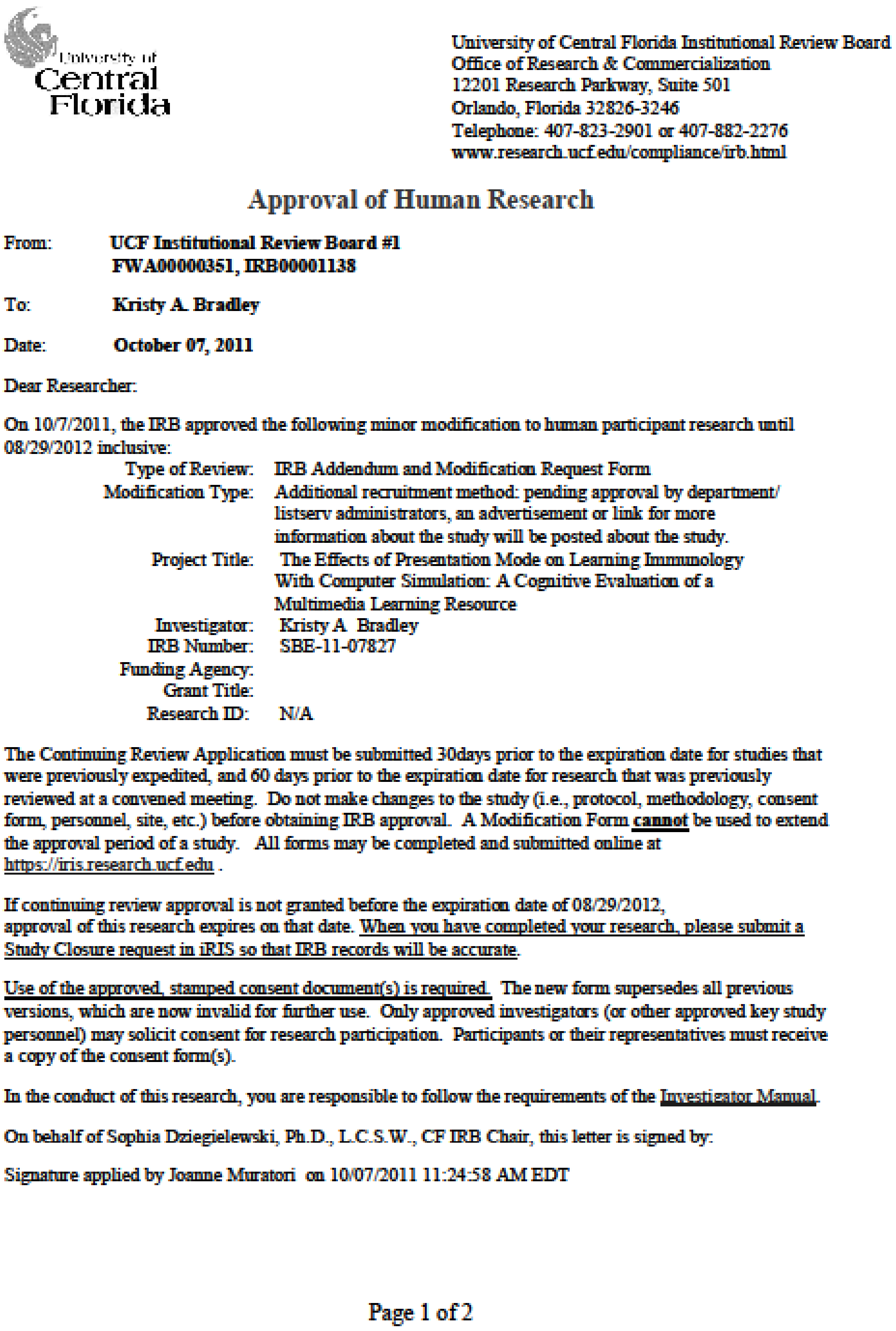
In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., CF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 09/07/2011 12:42:39 PM EDT

Joanne Muratori

IRB Coordinator



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Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Kristy A. Bradley**

Date: **October 07, 2011**

Dear Researcher:

On 10/7/2011, the IRB approved the following minor modification to human participant research until 08/29/2012 inclusive:

Type of Review: IRB Addendum and Modification Request Form
Modification Type: Additional recruitment method: pending approval by department/ listserv administrators, an advertisement or link for more information about the study will be posted about the study.
Project Title: The Effects of Presentation Mode on Learning Immunology With Computer Simulation: A Cognitive Evaluation of a Multimedia Learning Resource
Investigator: Kristy A Bradley
IRB Number: SBE-11-07827
Funding Agency:
Grant Title:
Research ID: N/A

The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 08/29/2012, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., CF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 10/07/2011 11:24:58 AM EDT

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Joanne Muratori

IRB Coordinator

LIST OF REFERENCES

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

Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short term memory. *Scientific American, 225,* 82-90.

Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556-559.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Bandura, A. (2000). Social-cognitive theory. In A. E. Kazdin (Ed.), *Encyclopedia of psychology* (Vol. 7, pp. 329-332). Washington, DC: American Psychological Association.

Bannert, M. (2002). Managing cognitive load – recent trends in cognitive load theory. *Learning and Instruction, 12,* 139-146.

Bennett, S., Maton, K., & Kervin, L. (2008). The 'digital natives' debate: A critical review of the evidence. *British Journal of Educational Technology, 39*(5), 775-786.

Betrancourt, M. (2007). The animation and interactivity principles in multimedia learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 287-296). New York: Cambridge University Press.

Black, A. (2010). Gen Y: Who they are and how they learn. *Educational Horizons, 88*(2), 92-101.

Boles, D. B. (2007). Predicting dual-task performance with the multiple resources questionnaire (MRQ). *Human Factors, 49*(1), 32-45.

Boles, D. B., & Adair, L. P. (2001a). The multiple resources questionnaire (MRQ). In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 1790–1794). Santa Monica, CA: Human Factors and Ergonomics Society.

Boles, D. B., & Adair, L. P. (2001b). Validity of the multiple resources questionnaire (MRQ). In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 1795–1799). Santa Monica, CA: Human Factors and Ergonomics Society.

Broadbent, D. E. (1957). A mechanical model for human attention and immediate memory. *Psychological Review, 64*(3), 205-215.

Bush, G. (2006). Learning about learning: From theories to trends. *Teacher Librarian, 34*(2), 14-18.

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

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

Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning: Evidence-based guidelines to manage cognitive load.* San Francisco, CA: Pfeiffer.

Cook, A. E., Zheng, R. Z., & Blaz, J. W. (2009). Measurement of cognitive load during multimedia learning activities. In R. Z. Zheng (Ed.), *Cognitive effects of multimedia learning* (pp. 34-50). Hershey, PA: Information Science Reference.

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24,* 87-185.

Domjan, M. (1996). *The essentials of conditioning and learning.* Pacific Grove, CA: Brooks/Cole Publishing Company.

Donaldson, J. A., & Knupfer, N. N. (2002). Education, learning, and technology. In P. L. Rogers (ed.), *Designing instruction for technology-enhanced learning* (pp. 19-54). Hershey, PA: Idea Group Publishing.

Driscoll, M. P. (2005). Cognitive information processing. In *Psychology of learning for instruction* (3rd ed., pp 71-152). Boston, MA: Pearson Education.

Gopher, D., & Braune, R. (1984). On the psychophysics of workload: Why bother with subjective measures? *Human Factors, 26*(5), 519-532.

Hancock, P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human factors, 31*(5), 519-537.

Harskamp, E. G., Mayer, R. E., & Suhre, C. (2007). Does the modality principle for multimedia learning apply to science classrooms? *Learning and Instruction, 17,* 465-477.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 139-183). Amsterdam: North-Holland.

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology, 21*, 713–729. doi: 10.1002/acp.1345

Jamet, E., & Le Bohec, O. (2007). The effect of redundant text in multimedia instruction. *Contemporary Educational Psychology, 32,* 588-598. doi: 10.1016/j.cedpsych.2006.07.001

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kalyuga, S. (2007). Enhancing instructional efficiency of interactive e-learning environments: A cognitive load perspective. *Educational Psychology Review, 19,* 387-399. doi:10.1007/s10648-10007-19051-10646

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

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

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

Kalyuga, S., Chandler, P., & Sweller, J. (2000). Incorporating learner experience into the design of multimedia instruction. *Journal of Educational Psychology, 92*(1), 126-136. doi: 10.1037//0022-0663.92.1.126

Kalyuga, S., Chandler, P., & Sweller, J. (2004). When redundant on-screen text in multimedia technical instruction can interfere with learning. *Human Factors, 46*(3), 567-581.

Kalyuga, S., & Sweller, J. (2004). Measuring knowledge to organize cognitive load factors during instruction. *Journal of educational Psychology, 96*(3), 558-568. doi: 10.1037/0022-0663.96.3.558

Kearsley, G. (2010). The theory into practice database. Retrieved from http://tip.psychology.org

Kirschner, P. A. (2002). Cognitive load theory: Implications of cognitive load theory on the design of learning. *Learning and Instruction, 12,* 1-10.

Leahy, W., Chandler, P., & Sweller, J. (2003). When auditory presentations should and should not be a component of multimedia instruction. *Applied Cognitive Psychology, 17,* 401-418. doi: 10.1002/acp.877

Learning Theories Knowledgebase (2011). *Constructivism at learning-theories.com.* Retrieved from http://www.learning-theories.com/constructivism.html

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

Low, R., Jin, P., & Sweller, J. (2009). Cognitive architecture and instructional design in a multimedia context. In R. Z. Zheng (Ed.), *Cognitive effects of multimedia learning* (pp. 1-16). Hershey, PA: Information Science Reference.

Margaryan, A., Littlejohn, A., & Vojt, G. (2011). Are digital natives a myth or reality? University students' use of digital technologies. *Computers & Education, 56,* 429-440.

Mason, J. A., Helton, L. R., & Dziegielewski, S. (2010). Psychosocial environmental relationships among MSW students in distance learning and traditional classrooms. *Journal of Social Service Research, 36,* 230-247. doi: 10.1080/01488371003707621

Mayer, R. E. (2005). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 183-200). New York: Cambridge University Press.

Mayer, R. E. (2009). *Multimedia learning* (2^{nd} ed.). New York, NY: Cambridge University Press.

Mayer, R. E., & Chandler, P (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 93*(2), 390-397. doi: 10.1037//0022-0663.93.2.390

Mayer, R. E., Dow, G. T., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*(4), 806-813. doi: 10.1037/0022-0663.95.4.806

Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187-198. doi:10.1037//0022-0663.93.1.187

Mayer, R. E., & Moreno, R. (2002). Aids to computer-based multimedia learning. *Learning and Instruction, 12,* 107-119.

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

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97.

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

Moreno, R. & Mayer, R. E. (2007). Interactive multimodal learning environments. *Educational Psychology Review, 19,* 309-326. doi: 10.1007/s10648-007-9047-2

Nygren, T. E. (1991). Psychometric properties of subjective workload measurement techniques: Implications for their use in the assessment of perceived mental workload. *Human Factors, 33*(1), 17-33.

Paas, F. G. W. C. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*(4), 429-434.

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

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P.W.M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63-71.

Paas, F. G. W. C, & van Merriënboer, J. J. G. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6*(4), 351-371.

Prensky, M. (2001a). Digital natives, digital immigrants. *On The Horizon, 9*(5), 1-6. Retrieved from http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part21.pdf

Prensky, M. (2001b). Do they really think differently? *On The Horizon, 9*(6), 1-6. Retrieved from http://www.marcprensky.com/writing/Prensky%20-%20Digital%20Natives,%20Digital%20Immigrants%20-%20Part22.pdf

Reid, G. B., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload. In P. A. Hancock, & N. Meshkati (Eds.), *Human mental workload* (pp. 185–218). Amsterdam: North-Holland.

Reisberg, D. (2001). *Cognition: Exploring the science of the mind* (2nd ed.). New York: W. W. Norton & Company.

Rey, G. D., & Buchwald, F. (2011). The expertise reversal effect: Cognitive load and motivational explanations. *Journal of Experimental Psychology: Applied 17*(1), 33-48. doi: 10.1037/a0022243

Rumelhart, D. E. (1980). Schemata: the building blocks of cognition. In R. J. Spiro, B. C. Bruce, & W. F. Brewer (Eds.), *Theoretical Issues in Reading Comprehension* (pp. 33-58). Hillsdale, NJ: Lawrence Erlbaum Associates.

Salas, E. & Cannon-Bowers, J. (2001). The science of training: A decade of progress. *Annual Review of Psychology, 52,* 471-499.

Sanders, M. S., & McCormick, E. J. (1993). Information input and processing. In *Human factors in engineering and design* (7th ed., pp. 47-90). New York: McGraw-Hill.

Scheiter, K., & Gerjets, P. (2007). Learner control in hypermedia environments. *Educational Psychology Review, 19,* 285-307. doi: 10.1007/s10648-007-9046-3

Schmidt-Weigand, F. (2009). The influence of visual and temporal dynamics on split attention: Evidences from eye tracking. In R. Z. Zheng (Ed.), *Cognitive effects of multimedia learning* (pp. 89-107). Hershey, PA: Information Science Reference.

Schmidt-Weigand, F., Kohnert, A., & Glowalla, U. (2010). Explaining the modality and contiguity effects: New insights from investigating students' viewing behavior. *Applied Cognitive Psychology, 24,* 226-237. doi: 10.1002/acp.1554

Skinner, B. F. (1985). Cognitive science and behaviorism. *The British Journal of Psychology, 76*, 291-301.

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

Sweller, J. (2005b). The redundancy principle in multimedia learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 159-167). New York: Cambridge University Press.

Sweller, J., & Chandler, P. (1991). Evidence for cognitive load theory. *Cognition and Instruction, 8*(4), 351-362.

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

Tabbers, H. K., & de Koeijer, B. (2010). Learner control in animated multimedia instructions. *Instructional Science*, *38*(5), 441-453. doi: 10.1007/s11251-009-9119-4

Treisman, A. M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12,* 242-248.

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of Educational Computing Research, 34*(3), 229-243.

Wickens, C. D. (1984). The structure of attentional resources. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention.* New York: Academic Press.

Wickens, C. D., & Carswell, C. M. (1997). Information processing. In G. Salvendy (Ed.), *Handbook of human factors and ergonomics* (2nd ed., pp. 89-129). New York: John Wiley & Sons.

Wiebe, E. N., Roberts, E., & Behrend, T. S. (2010). An examination of two mental workload measurement approaches to understanding multimedia learning. *Computers in Human Behavior, 26,* 474-481.