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The Cognitive Theory of Multimedia Learning

Stephen D. Sorden
Mohave Community College/Northern Arizona University

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Abstract
Multimedia learning is a cognitive theory of learning which has been popularized by the work of Richard E. Mayer and others. Multimedia learning happens when we build mental representations from words and pictures. The theory has largely been defined by Mayer’s cognitive theory of multimedia learning. Generally, the theory tries to address the issue of how to structure multimedia instructional practices and employ more effective cognitive strategies to help people learn efficiently. Baddeley’s model of working memory, Paivio’s dual coding theory, and Sweller’s theory of cognitive load are integral theories that support the overall theory of multimedia learning. The theory can be summarized as having the following components: (a) a dual-channel structure of visual and auditory channels, (b) limited processing capacity in memory, (c) three memory stores (sensory, working, long-term), (d) five cognitive processes of selecting, organizing, and integrating (selecting words, selecting images, organizing work, organizing images, and integrating new knowledge with prior knowledge), and theory-grounded and evidence-based multimedia instructional methods. Important considerations for implementing the theory are discussed, as well as current trends and future directions in research.

Introduction

The cognitive theory of multimedia learning was popularized by the work of Richard E. Mayer and other cognitive researchers who argue that multimedia supports the way that the human brain learns. They assert that people learn more deeply from words and pictures than from words alone, which is referred to as the multimedia principle (Mayer 2005a). Multimedia researchers generally define multimedia as the combination of text and pictures; and suggest that multimedia learning occurs when we build mental representations from these words and pictures (Mayer, 2005b). The words can be spoken or written, and the pictures can be any form of graphical imagery including illustrations, photos, animation, or video. Multimedia instructional design attempts to use cognitive research to combine words and pictures in ways that maximize learning effectiveness.

The theoretical foundation for the cognitive theory of multimedia learning (CTML)draws from several cognitive theories including Baddeley's model of working memory, Paivio's dual coding theory, and Sweller's Theory of Cognitive Load. As a cognitive theory of learning, it falls under the larger framework of cognitive science and the information-processing model of cognition. The information processing model suggests several information stores (memory) that are governed by processes that convert stimuli to information (Moore, Burton & Myers, 2004). Cognitive science studies the nature of the brain and how it learns by drawing from research in a number of areas including psychology, neuroscience, artificial intelligence, computer science, linguistics, philosophy, and biology. The term *cognitive* refers to perceiving and knowing. Cognitive scientists seek to understand mental processes such as perceiving, thinking, remembering, understanding language, and learning (Stillings, Weisler, Chase, Feinstein, Garfield, & Rissland, 1995). As such, cognitive science can provide powerful insight into human nature, and, more importantly, the potential of humans to develop more efficient methods using instructional technology (Sorden, 2005).

Key Elements of the Theory

The cognitive theory of multimedia learning (CTML) centers on the idea that learners attempt to build meaningful connections between words and pictures and that they learn more deeply than they could have with words or pictures alone (Mayer, 2009). According to CTML, one of the principle aims of multimedia instruction is to encourage the learner to build a coherent mental representation from the presented material. The learner's job is to make sense of the presented material as an active participant, ultimately constructing new knowledge.

According to Mayer and Moreno (1998) and Mayer (2003), CTML is based on three assumptions: *the dual-channel assumption*, the *limited capacity assumption*, and the active processing assumption. The dual-channel assumption is that working memory has auditory and visual channels based on Baddeley's (1986) theory of working memory and Paivio's (1986; Clark and Paivio, 1991) dual coding theory. Second, the limited capacity assumption is based on cognitive load theory (Sweller, 1988,1994) and states that each subsystem of working memory has a limited capacity. The third assumption is the active processing assumption which suggests that people construct knowledge in meaningful ways when they pay attention to the relevant material, organize it into a coherent mental structure, and integrate it with their prior knowledge (Mayer, 1996, 1999).

The Three Store Structure of Memory in CTML

CTML accepts a model that includes three memory stores known as sensory memory, working memory, and long-term memory. Sweller (2005) defines sensory memory as the cognitive structure that permits us to perceive new information, working memory as the cognitive structure in which we consciously process information, and long-term memory as the cognitive structure that stores our knowledge base. We are only conscious of information in long-term memory when it has been transferred to working memory. Mayer (2005a) states that sensory memory has a visual sensory memory that briefly holds pictures and printed text as visual images; and auditory memory that briefly holds spoken words and sounds as auditory images. Schnotz (2005) refers to sensory memory as sensory registers or sensory channels and points out that though we tend to view the dual channel sensors as eye-to-visual working memory and ear-to-auditory working memory, that it is possible for other sensory channels to introduce information to working memory such as "reading" with the fingers through Braille or a deaf person being able to "hear" by reading lips.

Working memory attends to, or selects information from sensory memory for processing and integration. Sensory memory holds an exact sensory copy of what was presented for less than .25 of a second, while working memory holds a processed version of what was presented for generally less than thirty seconds and can process only a few pieces of material at any one time (Mayer 2010a). Long-term memory holds the entire store of a person's knowledge for an indefinite amount of time. Figure 1 is a representation of how memory works according to Mayer's cognitive theory of multimedia learning.

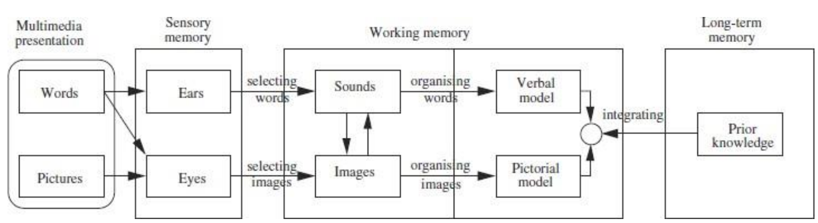

Figure 1 Mayer's Cognitive Theory of Multimedia Learning (Mayer 2010a)

Mayer (2005a) states that there are also five forms of representation of words and pictures that occur as information is processed by memory. Each form represents a particular stage of processing in the three memory stores model of multimedia learning. The first form of representation is the words and pictures in the multimedia presentation itself. The second form is the acoustic representation (sounds) and iconic representation (images) in sensory memory. The third form is the sounds and images in working memory. The fourth form of representation is the verbal and pictorial models which are also found in working memory. The fifth form is prior knowledge, or *schemas*, which are stored in long-term memory.

According to CTML, content knowledge is contained in schemas which are cognitive constructs that organize information for storage in long term memory. Schemas organize simpler elements that can then act as elements in higher order schemas. As learning occurs, increasingly sophisticated schemas are developed and learned procedures are transferred from controlled to automatic processing. Automation frees capacity in working memory for other functions. This process of developing increasingly complicated schemas that build on each other is also similar to the explanation given by Chi, Glaser, and Rees (1982) for the transition from novice to expert in a domain.

The Development of the Theory of Working Memory

The current conception of working memory in CTML grew out of Atkinson & Shiffrin's (1968) model of short term memory. The Atkinson & Shiffrin model was viewed primarily as a structure for temporarily storing information before it passed to long-term memory. Eventually, researchers began to question some of the assumptions of short-term memory and a few started to look for better explanations. Baddeley and Hitch (1974) subsequently proposed a more complex model of short-term memory which they called working memory. Their model for working memory was a system with subcomponents that not only held temporary information, but processed it so that several pieces of verbal or visual information could be stored and integrated.

Baddeley (1986, 1999) later proposed that there was an additional component in working memory called the central executive. According to the theory, the central executive controlled the two subcomponents of working memory, known as the *visuo-spatial sketch pad* and the *phonological loop*. The *central executive* also was responsible for controlling the overall system and engaging in problem solving tasks and focusing attention. Baddeley theorized that the central executive could transfer storage tasks to the two subcomponent systems in working memory, so that the central executive would continue to have capacity for performing more demanding selection and information processing tasks.

The visuo-spatial sketch pad is assumed to maintain and manipulate visual images. The phonological loop stores and rehearses verbal information. It has also been suggested that the phonological loop has an important function of facilitating the acquisition of language by maintaining a new word in working memory until it can be learned (Baddeley, Gathercole, & Papagno, 1998). Baddeley (2002) eventually proposed the addition of a third subsystem known as the *episodic buffer*, which has acquired some of the tasks that were originally attributed to the central executive (now seen as a purely attentional system). The episodic buffer functions as a storage structure which acts as a limited capacity interface to integrate multiple sources of information from other slave systems.

Sweller (2005) and Yuan, Steedle, Shavelson, Alonzo & Oppezo (2006) suggest that while there is strong evidence for the two main subcomponents in working memory, that there is less evidence for a central executive that consciously attends to information in sensory memory. Rather, Sweller suggests that schemas which exist in long-term memory serve as the executive function, ultimately directing working memory to attend to information that fits pre-existing schemas. Schemas determine which information enters working memory because we tend to pay attention to information that fits the knowledge that we already have. This would support the idea that our paradigms cause us to focus on information that fits our existing beliefs, while ignoring information that does not fit neatly into our understanding of the world.

Meaningful Learning

Mayer (2010a) argues that meaningful learning from words and pictures happens when the learner engages in five cognitive processes:

1. selecting relevant words for processing in verbal working memory
2. selecting relevant images for processing in visual working memory
3. organizing selected words into a verbal model
4. organizing selected images into a pictorial model
5. integrating the verbal and pictorial representations with each other and with prior knowledge.

These cognitive processes in working memory determine which information is attended to or selected, which knowledge is retrieved from long term memory and integrated with new the information to construct new knowledge, and ultimately, which bits of new knowledge are transferred to long-term memory. Knowledge that is constructed in working memory is transferred to long-term memory through the process of *encoding* (Mayer, 2008b). However, Dwyer & Dwyer (2006) caution that proper encoding requires rehearsal and since rehearsal takes time, the multimedia lesson must allow an adequate period for incubation or it can be ineffective. Hasler, Kersten, & Sweller (2007) add that this is why learner control is important when using animation in multimedia learning.

Mayer (2009) distinguishes meaningful learning from “no learning” and “rote learning” and describes it as active learning where the learner constructs knowledge. Meaningful learning is demonstrated when the learner can apply what is presented in new situations, and students perform better on problem-solving transfer tests when they learn with words and pictures. Mayer (2008b) also identifies two types of transfer: *transfer of learning* and *problem-solving transfer*. Transfer of learning occurs when previous learning affects new learning. Problem solving transfer occurs when previous learning affects the ability to solve new problems. Mayer defines learning as a “change in knowledge attributable to experience” (2009, p. 59). Learning is personal and cannot be directly observed because it happens with the learner’s cognitive system. It must be inferred through a change in behavior such as performance on a task or test.

Cognitive Load

The limited capacity assumption states that there is a limit to the amount of information that can be processed at one time by working memory. In other words, learning is hindered when cognitive overload occurs and working memory capacity is exceeded (De Jong, 2010). DeLeeuw & Mayer (2008) theorize that there are three types of cognitive processing (essential, extraneous, and generative) and place them in the *triarchic model of cognitive load*. Mayer (2009) made this model the organizing framework for the cognitive theory of multimedia learning and stated that a major goal of multimedia learning and instruction is to “manage essential processing, reduce extraneous processing and foster generative processing” (p. 57). The model is heavily based on Sweller’s cognitive load theory (Chandler & Sweller, 1991; Sweller, 1988, 1994).

According to Sweller, Van Merrienboer, and Paas (1998), there are three types of cognitive load: intrinsic, extraneous, and germane. Intrinsic cognitive load occurs during the interaction between the nature of the material being learned and the expertise of the learner. The second type, extraneous cognitive load, is caused by factors that aren't central to the material to be learned, such as presentation methods or activities that split attention between multiple sources of information, and these should be minimized as much as possible. The third type of cognitive load, germane cognitive load, enhances learning and results in task resources being devoted to schema acquisition and automation. Intrinsic cognitive load cannot be manipulated, but extraneous and germane cognitive load can.

In the triarchic model of cognitive load, essential processing (intrinsic load) relates to the essential material or information to be learned. Extraneous processing (extrinsic load) does not serve the instructional goal or purpose and reduces the chances that transfer of learning will occur. Generative processing (germane cognitive load) is aimed at making sense of the presented material. It is the activity of organizing and integrating information in working memory.

De Jong (2010) has called into question whether there is truly a distinction between intrinsic (essential) and germane (generative) cognitive load, writing that if "intrinsic load and germane load are defined in terms of relatively similar learning processes, the difference between the two seems to be very much a matter of degree, and possibly non-existent" (p. 111). Deleeuw and Mayer (2008), however, did report finding that extraneous, essential, and generative processing appear to be able to be measured by different assessment instruments, suggesting that they are three distinct constructs.

The Science of Instruction

The previous sections describe what Mayer (2009) calls the *science of learning*, while this section explains what Mayer calls the *science of instruction* and defines as the "creation of evidence-based principles for helping people learn" (2009, pp. 29), or more simply as the "scientific study of how to help people learn" (Mayer, 2010a, p. 543). Mayer insists that research on multimedia instruction must be *theory-grounded* and *evidence-based*. Theory-grounded means that each principle, method and concept is derived from a theory of multimedia learning. Evidence-based means that each principle, method and concept is supported by an empirical base of replicated findings from rigorous and appropriate research studies, which yields testable predictions. Mayer (2011a) subsequently adds the *science of assessment* to the sciences of learning and instruction to form what he calls the “Big Three” (p. 2).

As part of his evidence-seeking efforts for the science of instruction, Mayer (2009) identifies the following twelve multimedia instructional principles which were developed from nearly 100 studies over the past two decades:

- Coherence Principle – People learn better when extraneous material is excluded rather than included.
- Signaling Principle – People learn better when cues that highlight the organization of the essential material are added.
- Redundancy Principle – People learn better from graphics and narration than from graphics, narration, and printed text.
- Spatial Contiguity Principle – People learn better when corresponding words and pictures are placed near each other rather than far from each other on the page or screen.
- Temporal Contiguity Principle – People learn better when corresponding words and pictures are presented at the same time rather than in succession.
- Segmenting Principal – People learn better when a multimedia lesson is presented in user-paced segments rather than as a continuous unit.
- Pre-training Principle – People learn more deeply from a multimedia message when they receive pre-training in the names and characteristics of key components.
- Modality Principle – People learn better from graphics and narration than from graphics and printed text.
- Multimedia Principle – People learn better from words and pictures than from words alone.
- Personalization Principle – People learn better from a multimedia presentation when the words are in conversational style rather than in formal style.
- Voice Principle – People learn better when the words in a multimedia message are spoken by a friendly human voice rather than a machine voice.
- Image Principle – People do not necessarily learn more deeply from a multimedia presentation when the speaker’s image is on the screen rather than not on the screen.

As mentioned earlier, these twelve principles are grouped ina framework based on the three types of cognitive load (Mayer 2009):

- reducing extraneous processing – coherence, signaling, redundancy, spatial contiguity, temporal contiguity
- managing essential processing – segmenting, pre-training, modality
- fostering generative processing – multimedia, personalization, voice, image

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Applying the Cognitive Theory of Multimedia Instruction

Once we understand the science of learning and the science of instruction, the next question becomes how to apply the principles in order to foster meaningful learning. See Mayer's (2011a) *Applying the Science of Learning* for a good overview of what to consider when applying the methods described in this chapter, as well as others,

This section looks at what to keep in mind as the instructional methods in CTLM are implemented. In addition to applying the twelve principles and the advanced principles presented in this chapter and in Mayer (2005a, 2009, 2011b), the instructional designer should be aware of the information presented in this section when creating multimedia instruction. These theories come from the cognitive theory of multimedia learning, cognitive load theory, and cognitive science in general. It should be remembered that they are theories, and as such should be applied with caution, but all of them have research and a theoretical background that make them worth considering as guidelines for creating better instruction.

The principles of multimedia learning should be viewed as instructional methods whose primary goal is to foster meaningful learning. An instructional method is a way of presenting a lesson; it does not change the content of the lesson—the covered content is the same. As discussed previously, the principles should not be viewed as absolute rules that have to be applied equally in every situation. They are guidelines that should be adjusted depending on the intended audience, the goals of the instruction, and boundary conditions such as the expertise level of the learner. Most important, the theory is a learner-centered learning theory (Mayer, 2009).

Learner-Centered Focus

A critical perspective to maintain while designing multimedia lessons according to CTML is that the multimedia instructional methods are learner-centered—they are not technology-centered approaches. Mayer (2009) reminds us that multimedia can be as simple as a still image with words and that it is the instructional method, not the technology that matters. Multimedia instructional designers often fall victim to letting the technology drive the instructional design, rather than looking at the design from the perspective, and limitations, of the learner.

Moreno (2006a) expressed this idea when she distinguished between a *method-affects-learning* hypothesis versus a *media-affects-learning* hypothesis. A media-affects-learning approach could best be described as what occurred in the 20th Century when state-of-the-art technologies such as radio, television, computers, and the Internet were introduced into education with the assumption that they would improve education simply because they were better tools than had previously been available.

Managing Cognitive Load

Because the principles of CTML are organized around the three types of cognitive load, designing instruction according to cognitive load theory (CLT) research findings is important if you are designing according to CTML. Mayer, Fennell, Farmer, and Campbell (2004) cite evidence that two important ways to promote meaningful learning are to design activities that reduce cognitive load, which frees working memory capacity for deep cognitive processing during learning, and to increase the learner's interest, which encourages the learner to use this freed capacity for deep processing during learning. CLT suggests that for instruction to be effective, care must be taken to design instruction in a way as to not overload the brain's capacity for processing information.

CLT suggests that instructional techniques that require students to engage in activities that aren't directed at schema acquisition and automation can quickly exceed the limited capacity of working memory and hinder learning objectives. In simple terms, this means that you shouldn't create unnecessary activities in connection with a lesson that require excessive attention or concentration that may overload working memory and prevent one from acquiring the essential information that is to be learned. This is an important guideline in any form of instruction, but it is an essential rule in multimedia instruction because of the ease with which distractions can be incorporated. Instructional designers should not fill this limited capacity with unnecessary, flashy bells and whistles (Sorden, 2005).

An example of what this means for multimedia instructional design is that the layout should be visually appealing and intuitive, but that the activities should remain focused on the concepts to be learned, rather than trying too much to entertain. This is especially true if the entertainment is time consuming to construct and complicated for the learner to master. Working memory can be overloaded by the entertainment or activity before the learner ever gets to the concept or skill to be learned. Mayer (2009) states that effective "instructional design depends on techniques for reducing extraneous processing, managing essential processing, and fostering generative processing" (p. 57).

Schnotz and Kürschner (2007) echo this idea by stating that techniques to simply reduce cognitive load can be counterproductive. They argue that learning tasks should be adapted to the learner's zone of proximal development which in turn depends on the learner's level of expertise, and that intrinsic and germane cognitive load should be promoted while extraneous cognitive load is reduced. De Jong (2010) states that the three main recommendations that cognitive load theory has contributed to the field of instructional design are: "present material that aligns with the prior knowledge of the learner (intrinsic load), avoid non-essential and confusing information (extraneous load), and stimulate processes that lead to conceptually rich and deep knowledge (germane load)" (p. 111). These cognitive load processes occur simultaneously in working memory, are limited in capacity, and can only occur at the expense of the other two. If true, this creates important considerations for multimedia learning.

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Conclusion

The cognitive theory of multimedia learning has progressed over the past two decades and is poised to become a mature, robust theory as it enters its third decade. Fortunately, the theoretical cognitive foundations upon which the theory is based go much further back and have contributed heavily to its framework of the "big three" sciences, as well as the structure given to its principles by the triarchic theory of cognitive load. Together, these two areas of study form what we generally understand today to be the cognitive theory of multimedia learning.

The theory is expanding into exciting new areas that will allow it to continue to evolve. Its learner-centered and cognitive-constructivist orientation makes it very relevant in current educational applications. The fact that it focuses on finding effective instructional methods rather than a specific technology makes it a dynamic theory that will allow it to expand well beyond the life cycle of any particular technology.

While the theory continues to have problematic and unanswered areas, the researchers acknowledge this and expect that the theory will continue to develop and change as new and better research techniques are developed for the study of how we learn and how the human brain works. It is an exciting field that is developing very quickly due to advances in technology and neuroscience, and there is a great need for new researchers to contribute new scientific studies to the development of the theory, the principles, the boundary conditions, and finally, the “big three” sciences of learning, instruction, and assessment themselves.

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