Applications of Cognitive Learning Theory to the Design of Multimedia Learning

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Abstract

Major cognitive theories related to the design of multimedia learning are discussed. The types of learning to which cognitive learning theory best applies are noted. The applicability of cognitive theory to multimedia learning based on other learning theories is also discussed. Overviews of cognitive load theory and the cognitive theory of multimedia learning are provided, and the application of each to the design of multimedia learning is discussed. Future directions for cognitive learning theory are briefly noted.

Keywords: cognitive learning theory, cognitive load theory, cognitive theory of multimedia learning

Applications of Cognitive Theory to the Design of Multimedia Learning

Richard Mayer, a prominent researcher in the field of cognitive learning and multimedia design, has noted, “Multimedia messages that are designed in light of how the human mind works are more likely to lead to meaningful learning than those that are not” (Mayer, 2005). This holds true no matter what overarching theory may be used for the development of a multimedia lesson. This paper lays out what cognitive theory has to say about the way the human mind works, and attempts to build a bridge between that theory and the design of multimedia learning.

This paper examines the types of learning to which cognitive theory may apply, then examines two of the major cognitive learning theories: cognitive load theory and the cognitive theory of multimedia learning. It makes recommendations based on each for the design of multimedia learning activities. Finally, it briefly examines some new directions in the application of cognitive learning theory to multimedia learning.

Types of Learning to Which Cognitive Theory May Apply

With the proliferation of learning theories over the last several decades, there is a growing awareness that different types of learning may be better explained by some learning theories than by others. Ertmer and Newby (1993) compared behaviorism, cognitivism, and constructivism and made suggestions about the types of learning that are best explained by each theory. They provided a breakdown from two different perspectives: based on a low-to-high knowledge continuum and based on the requirements of the learning task. Table 1 summarizes this breakdown.

Table 1

Learning Theories Identified with Various Learning Types

	Learning Theory		
Factor	Behaviorism	Cognitivism	Constructivism
Knowledge continuum	Content mastery (knowing what)	Problem-solving: application of rules (knowing how)	Ill-defined problems
Learning task requirements	Rote memorization	Classifications, rule or procedural executions	High processing

Note: Based on Ertmer & Newby (1993).

In summary, learning tasks that involve problem-solving, classification, and execution of rules or procedures are particularly well-suited to a cognitive approach. However, beyond a pure cognitive approach, cognitive learning theories offer many insights about how the human brain processes information that can complement almost any other learning approach that uses multimedia as part of its presentation (Sweller, 1998; Mayer, 2005). The bulk of this paper will examine two such theories: cognitive load theory (CLT) and the cognitive theory of multimedia learning (CTML).

Cognitive Load Theory

CLT was chiefly developed by John Sweller (Sweller, 1988, and Sweller, van Merrienboer, & Paas, 1998), but has its roots in the work of George Miller (Miller, 1956) and Alan Baddeley (Baddeley, 1992). The basic premise is that memory is composed of a limited working memory and an essentially unlimited long-term memory. CLT is concerned with ways to address the limitations of working memory and thus promote more effective learning (Kirschner, 2002). This section examines the two different types of memory, different types of cognitive load, some effects of cognitive load, and finally, the instructional design implications of CLT.

Types of Memory

Sweller, et al. (1998) describe short-term or working memory as consciousness, and state that “humans are conscious of and can monitor only the contents of working memory. All other cognitive functioning is hidden from view unless and until it can be brought into working memory” (p. 252). Miller (1956) determined that working memory can only hold around seven items at a time. Sweller, et al. note that when you take working with information into account (e.g., organizing or comparing it), the average person can probably only hold two or three items at a time. One of the key implications of a limited working memory is that it is easily overloaded. If learners are presented with so much information that it fills or overfills their working memory, then there will be no capacity left to carry out reasoning tasks.

Baddeley (1992) suggested that working memory is composed of one part that deals with auditory information, another part that deals with visual information, and a central executive that governs the other two parts. By presenting some information in auditory form and other information in visual form, working memory capacity can be increased to a limited degree.

Because working memory is limited and transitory, theorists have pointed to long-term memory as the place where permanent knowledge is stored. Kirschner (2002) states:

> *Long-term memory* (LTM) is, in contrast, what you use to make sense of and give meaning to what you are doing now. It is the repository for more permanent knowledge and skills and includes all things in memory that are not currently being used but which are needed to understand. (p. 2)

Humans do not have direct access to long-term memory. Elements of long-term memory must first be transferred into working memory for access and processing (Sweller, et al., 1998).

Knowledge in long-term memory is stored in *schemas*. These can be large knowledge structures that organize information based on how it will be used. Although a sophisticated schema may comprise a huge amount of information, it is processed as a single entity by working memory. Thus, having a large number of complex schemas reduces working memory load. A key goal of CLT is to reduce cognitive load in order to provide working memory capacity to devote to the building and automation of schemas (Kirschner, 2002; Sweller, et al., 1998).

Types of Cognitive Load

Sweller, et al. (1998) defined three types of cognitive load: intrinsic cognitive load, extrinsic cognitive load, and germane cognitive load.

Intrinsic cognitive load. This type of cognitive load is a function of the material to be learned and the number of elements that must be processed in working memory simultaneously, which is determined by the element interactivity of the material. For example, learning foreign language vocabulary has a low element interactivity. Each word has an associated meaning that is independent of the meaning of the other words. On the other hand, learning the grammar of a foreign language has a high element interactivity because the relationship of each word to the others in a sentence matters, requiring all of the words to be considered as a group. Instructional designers cannot reduce intrinsic cognitive load because it is a characteristic of the material to be learned (Sweller, et al., 1998).

Intrinsic cognitive load is also affected by schemas the learner may possess. For instance, beginning readers need to sound out each letter in a word, then string together a series of words into a meaningful sentence. Advanced readers have sophisticated schemas for making sense of letters, words, and sentences. Thus, a reading activity that has high element interactivity for a beginning reader will have low element interactivity for an advanced reader. It is critical for instructional designers to consider the characteristics of their learners when trying to determine intrinsic cognitive load (Sweller, et al., 1998).

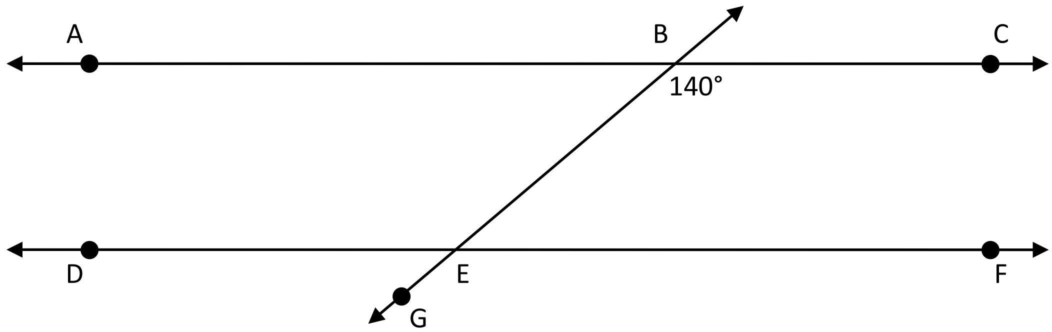
Extrinsic cognitive load. This type of cognitive load is the load imposed by the presentation of the material. If the instructional design is poor (e.g., if the material is poorly organized, or too much is presented at once), it will add cognitive load. This type of cognitive load can be reduced through good instructional design (Sweller, et al., 1998).

Germane cognitive load. The final type of cognitive load, germane cognitive load, is the effort required for building schemas. Germane cognitive load is also under the control of instructional designers. Good instructional designers will work to decrease extrinsic cognitive load and increase germane cognitive load, as long as it does not exceed working memory capacity (Sweller, et al., 1998).

Cognitive Load Effects

Sweller and his colleagues have done extensive research into some effects tied to cognitive load that are relevant for the design of effective instruction. These effects include the goal-free effect, worked-example effect, split-attention effect, modality effect, redundancy effect, and variability effect (Sweller et al., 1998). Three of the most generally applicable effects are discussed below.

Split-attention effect. The split-attention effect occurs when a picture and related text information are presented separately, as shown in Figure 1.



In the figure above, find the measure of ∠DEG.

Solution:

∠ABE + ∠EBC = 180°	Definition of supplementary angles
∠ABE + 140° = 180°	
∠ABE = 40°	
∠ABE = ∠BEF	Alternate interior angles are equal
∠BEF = 40°	
∠BEF = ∠DEG	Vertical angles are equal
∠DEG = 40°	

Figure 1. Example showing the split-attention effect.

In the example, neither the diagram nor the text below it make much sense in isolation. They only become meaningful when the learner integrates the information in the diagram and the text below it. The learner must read a statement and hold it in working memory while searching the diagram for the referents, which is cognitively demanding (Sweller, et al., 1998). Now contrast it with Figure 2.

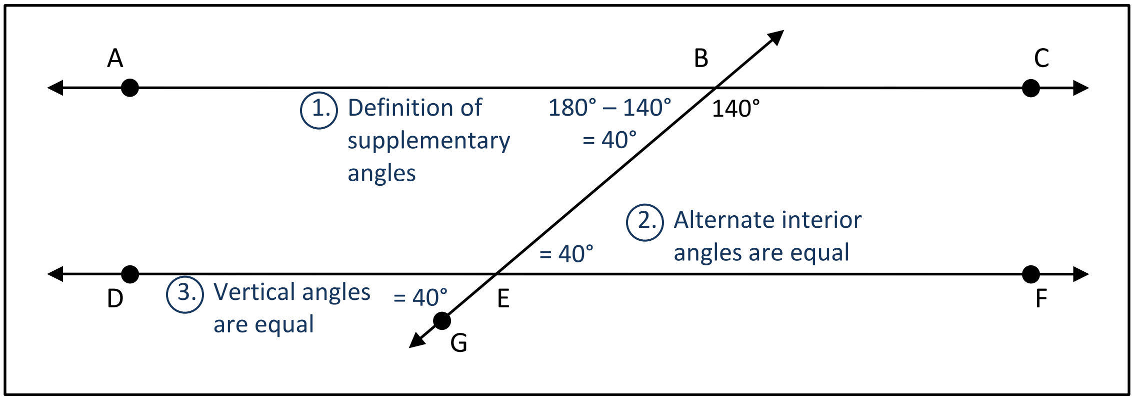


Figure 2. Example showing the physical integration of information to eliminate the split-attention effect.

Figure 2 shows the same information, but the text has been physically integrated with the diagram, eliminating the need for the learner to mentally integrate the information. This reduces the cognitive load (Sweller et al., 1998).

Modality effect. The modality effect demonstrates another approach to the issue demonstrated in the split-attention effect. As noted above, Baddeley (1992) provided evidence that working memory is divided into two parts. One part handles visual information and the other part handles auditory information. Working memory can be extended by presenting some information in a visual mode and some in an auditory mode. For example, rather than presenting a diagram with text, the same diagram can be presented with audio narration. Splitting the processing between two modes reduces the load on working memory (Sweller, et al., 1998).

Redundancy effect. The redundancy effect is the opposite of the split-attention effect. In the split-attention effect, two sources of information such as a picture and text must be integrated in order to make sense. In the redundancy effect, two sources of information can be understood in isolation. If they are integrated, learners have a hard time ignoring the additional information, which increases cognitive load. It is often better to eliminate the redundant information completely (Sweller, et al., 1998).

Instructional Design Implications

CLT has a number of implications for the instructional design of multimedia learning. First, instructional designers should be attentive to the intrinsic cognitive load imposed by learning tasks. This can be gauged from an analysis of the level of element interactivity of the material and an analysis of the learners’ level of schema development. In addition, instructional designers should reduce extrinsic cognitive load whenever possible. Effective strategies include reducing the split-attention effect by physically integrating material that cannot be understood in isolation, or taking advantage of the modality effect by presenting some of the content in audio form. Likewise, instructional designers should critically analyze learning materials for redundancy and eliminate it.

Finally, after controlling for extraneous cognitive load, instructional designers should make use of available working memory to add germane cognitive load to aid in schema building. Kirschner (2002) states:

> The basic assumption is that an instructional design that results in unused working memory capacity because of a low intrinsic CL [cognitive load] imposed by the instructional materials and/or low extraneous CL due to appropriate instructional procedures may be further improved by encouraging learners to engage in conscious cognitive processing that is directly relevant to schema construction. (p. 5)

Cognitive Theory of Multimedia Learning

CTML was developed by Richard Mayer and colleagues at the University of California at Santa Barbara (Mayer, 2005). It has much in common with CLT, and so this paper will note but not dwell on similar features.

Mayer defines a multimedia instructional message as “a communication containing words and pictures intended to foster learning” (Mayer, 2005, p. 32). Although CTML is most often applied to computer-based learning, the theory can apply to any medium, including print, video, and interactive simulations (Mayer, 2005).

CTML Assumptions

There are three assumptions behind CTML: dual channels, limited capacity, and active processing (Mayer, 2005).

Dual channels. CTML assumes similar auditory and visual channels as CLT. However, CTML makes a distinction between *sensory modalities* and *presentation modes*. As Mayer uses the terms, the sensory mode refers to whether the material is presented visually (including pictures, animations, video, and on-screen text) or auditorily (narration and sound effects). The presentation mode refers to the representation in working memory. For instance, a learner may convert words on the screen (visual) into sounds (auditory), or convert a narrated description (auditory) into a mental image (visual) (Mayer, 2005).

Limited capacity. CTML assumes the same limited capacity for working memory as CLT.

Active processing. Mayer asserts that we are not simply human tape recorders, filing information for later retrieval. Rather, “humans are active processors who seek to make sense of multimedia presentations” (2005, p. 36). Mayer further identifies “three processes that are essential for active learning[:] selecting relevant material, organizing selected material, and integrating selected material with existing knowledge (Mayer, 1996, 2001; Wittrock, 1989)" (2005, p. 37).

Memory Stores

CTML has the same working memory and long-term memory assumptions as CLT. However, CTML also adds a sensory memory store. Pictures and printed text enter through a visual sensory memory; sounds and spoken words enter through an auditory sensory memory. The contents of sensory memory are held briefly, then through cognitive processes (see below), some of the information may pass into working memory and long-term memory. Mayer presents the diagram shown in Figure 3 to illustrate the different memory stores and cognitive processes. The arrows from Words to Ears and Eyes illustrate the fact that words may be in the form of text or narration (Mayer, 2005).

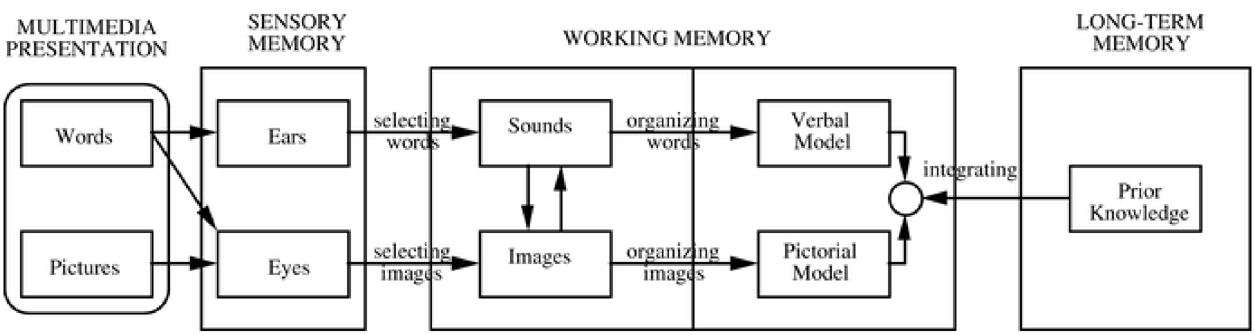


Figure 3. Diagram illustrating the cognitive theory of multimedia learning. (Mayer, 2005, p. 37)

Cognitive Processes

For learning to occur, there are five cognitive processes a learner must engage in. After receiving sensory input, the learner must select relevant words and select relevant images. Because working memory is limited, learners typically cannot attend to all of the words and images presented, and therefore a selection process takes place. Next, the selected words are organized into a verbal model, and the selected images are organized into a pictorial model. Note that during this process, some sounds may be converted to images or vice versa. (For example, converting a verbal description into a mental image.) Finally, the verbal and pictorial models are integrated with each other and with prior knowledge, then stored as a schema in long-term memory (Mayer, 2005).

Instructional Design Applications

Mayer and his colleagues have done a great deal of research on the implications of CTML for multimedia design, and have used multimedia design to confirm the predictions of CTML. A number of principles that have emerged from this research program.

Multimedia principle. “Students learn more deeply from multimedia presentations involving words and pictures than from words alone” (Mayer, 2002, p. 63).

Contiguity principle. Present corresponding words and pictures simultaneously, rather than presenting them sequentially. For example, rather than reading a description of a process and then seeing an animation of it, use audio narration during the animation to describe the process (Mayer, 2002).

Coherence principle. A common misconception is that adding interesting but irrelevant details to a presentation will better engage learners. In fact, it increases extraneous cognitive load leading to less effective learning. Therefore, extraneous elements should be removed from multimedia presentations (Mayer, 2002).

Modality principle. Animation combined with narration is more effective than animation combined with on-screen text. In the latter case, the visual channel becomes overloaded. Using narration moves some of the input to the auditory channel, reducing cognitive load (Mayer, 2002).

Redundancy principle. This principle is essentially the same as Sweller's redundancy effect. However, Mayer's is more limited, stating simply that animation with narration only is more effective than animation with narration and on-screen text (Mayer, 2002).

Personalization principle. This principle states that learners learn better "when words are presented in a conversational style than in an expository style" (Mayer, 2002, p. 67).

Interactivity principle. Allowing learners to have control over the pace of a presentation (e.g., with a Continue button) improves learning. This control helps to prevent cognitive overload, and allows learners to engage in the cognitive processes noted above (Mayer, 2002).

Signaling principle. Emphasizing key terms and adding transition words or other forms of signaling (e.g., "first," "second," etc.) improves learning by helping students with the sense-making process (Mayer, 2002).

Future Directions

Cognitive learning theory continues to advance. One emerging theory is embodied cognition, which examines the relationship between physical movement, gestures, and actions and the formation of concepts. Researchers are experimenting with touchpad computing devices, interactive whiteboards, haptic feedback systems, and systems like the Microsoft Kinect. Research shows that in many cases, learning is improved by the addition of physical stimulus (Black, Segal, Vitale, & Fadjo, 2012). Perhaps we should not be surprised; after all, if working memory has visual and auditory components, it makes sense to consider whether it may also have components based on touch, taste, and smell. And if it does, then perhaps these additional channels can provide additional ways to reduce cognitive load and therefore improve learning. It is interesting to note that Moreno and Mayer (2007) have revised their CTML diagram to include tactile, olfactory, and gustatory sensory memory components, though they say little about the new sensory components.

Conclusions

Cognitive learning theory has a great deal to offer to designers of multimedia learning. While it may be that some learning theories are best suited for certain types of learning, cognitive learning theory offers critical insights into how humans process information that are important for any multimedia learning project.

CLT points to limits in our ability to absorb and process information. It offers practical guidance in how to reduce extrinsic cognitive load through attention to the split-attention effect, the modality effect, and the redundancy effect. It recommends the careful introduction of germane cognitive load to aid in schema building.

CTML builds on CLT by adding the concept of dual channels in working memory—visual and auditory. It also places an emphasis on active processing by the learner, and provides insight into five cognitive processes that learners engage in. In addition, it offers eight principles, all backed by empirical research, for the design of multimedia learning.

Finally, the future is bright for cognitive learning theory, with current researchers investigating other sensory channels such as touch and movement.

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