A Cognitive Theory of Multimedia Learning: Implications for Design Principles

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Research on educational technologies--ranging from motion pictures to computer-based tutoring systems--documents a disapointing history in which strong claims for a new technology are followed by large-scale implementations which eventually fail (Cuban, 1986; Mayer, in press). For example, in 1922, the famous inventor Thomas Edison proclaimed that "the motion picture is destined to revolutionize our educational system and that in a few years it will supplant...the use of textbooks" (cited in Cuban, 1986, p. 9). Yet, in reviewing the role of motion pictures in schools over the decades since Edison's grand predictions, Cuban (1986, p. 17) concluded that "most teachers used films infrequently in classrooms." Similarly, fifty years later in the 1970s, the game-like computer-assisted instruction (CAI) programs that were tauted as the wave of the future in education eventually proved to be no more effective than teacher-based modes of instruction (Cognition and Technology Group at Vanderbilt, 1996). Today, similarly strong claims are being made for the potential of **multimedia** learning environments.

How canwe avoid a trail of broken promises concerning the educational benefits of new educational technologies such as **multimedia** learning evironments? A reasonable solution is to use instructional technology in ways that are grounded in research-based theory. The overarching theme of this paper is that effective use of a new instructional technology must be guided by a research-based theory of how students learn. Fortunately, advances in **cognitive** psychology provide the starting point for such theories. We are convinced that one of the most important avenues of **cognitive** psychology is to understanding how technology--such as **multimedia**--can be used to foster student learning. As an example, in this paper we provide a research-based review of five principles of **multimedia** design.

We begin with a **cognitive** theory of **multimedia** learning (Mayer, 1997), as outlined in Figure 1. The theory draws on Paivio's (1986; Clark & Paivio, 1991) dual coding theory,

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Baddeley's (1992) model of working memory, Sweller's (Chandler & Sweller, 1991; Sweller, Chandler, Tierney & Cooper, 1990) **cognitive** load theory, Wittrock's (1989) generative theory, and Mayer's (1996) SOI model of meaningful learning. According to the theory, the learner possesses a visual information processing system and a verbal information processing, such that auditory narration goes into the verbal system whereas animation goes into the visual system.

In **multimedia** learning the learner engages in three important **cognitive** processes. The first **cognitive** progress, selecting, is applied to incoming verbal information to yield a text base and is applied to incoming visual information to yield an image base. The second **cognitive** process, organizing, is applied to the word base to create a verbally-based model of the to-be-explained system and is applied to the image base to create a visually-based model of the to-be-explained system. Finally, the third process, integrating, occurs when the learner builds connections between corresponding events (or states or parts) in the verbally-based model and the visually-based model. The model is explained more fully in Mayer (1997), and has generated a series of experiments yielding five major principles of how to use **multimedia** to help students understand a scientific explanation. Each principle of **multimedia** design is subject to further research.

Multiple Representation Principle: Its is better to present an explanation in words and pictures than solely in words. The first principle is simply that it is better to present an explanation using two modes of representation rather than one. For example, students who listened to a narration explaining how a bicycle tire pump works while also viewing a corresponding animation generated twice as many useful solutions to subsequent problem-solving transfer questions than did students who listened to the same narration without viewing any animation (Mayer & Anderson, 1991, 1992). Similarly, students who read a text containing captioned illustrations placed near the corresponding words generated about 65% more useful solutions on a subsequent problem-solving transfer test than did students who simply read the text (Mayer, 1989; Mayer & Gallini, 1990). We call this result a **multimedia**

effect. The **multimedia** effect is consistent with a **cognitive** theory of **multimedia** learning because students given **multimedia** explanations are able to build two different mental representations--a verbal model and a visual model--and build connections between them.

Contiguity Principle: When giving a **multimedia** explanation, present corresponding words and pictures contiguously rather than separately. The second principle is that students better understand an explanation when corresponding words and pictures are presented at the same time than when they are separated in time. For example, students who listened to a narration explaining how a bicycle tire pump works while also viewing a corresponding animation generated 50% more useful solutions to subsequent problem-solving transfer questions than did students who viewed the animation before or after listening to the narration

(Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994). Similarly, students who read a text explaining how tire pumps work that included captioned illustrations placed near the text generated about 75% more useful solutions on problem-solving transfer questions than did students who read the same text and illustrations presented on separate pages (Mayer, 1989; Mayer, Steinhoff, Bower, & Mars, 1995). We call this result a contiguity effect, and similar patterns have been noted by other researchers (Chandler & Sweller, 1991; Sweller & Chandler, 1994; Sweller, Chandler, Tierney and Cooper, 1990; Paas & Van Merrienboer, 1994). This result is consistent with the **cognitive** theory of **multimedia** learning because corresponding words and pictures must be in working memory at the same time in order to facilitate the construction of referential links between them.

Split-Attention Principle: When giving a **multimedia** explanation, present words as auditory narration rather than as visual on-screen text. The third principle is that words should be presented auditorily rather than visually. For example, students who viewed an animation depicting the formation of lightning while also listening to a corresponding narration generated approximately 50% more useful solutions on a subsequent problem-solving transfer test than did students who viewed the same animation with corresponding on-screen text consisting of the same words as the narration (Mayer & Moreno, in press). Sweller and his colleagues call this a

split attention effect (Chandler & Sweller, 1991; Mousavi, Low & Sweller, 1995; Sweller, Chandler, Tierney and Cooper, 1990). This result is consistent with the **cognitive** theory of **multimedia** learning because the on-screen text and animation can overload the visual information processing system whereas narration is processed in the verbal information processing system and animation is processed in the visual information processing system.

Individual Differences Principle: The foregoing principles are more important for low-knowledge than high-knowledge learners, and for high-spatial rather than low-spatial learners.

The fourth principle is that **multimedia** effects, contiguity effects, and split-attention effects depend on individual differences in the learner. For example, students who lack prior knowledge tended to show stronger **multimedia** effects and contiguity effects than students who possessed high levels of prior knowledge (Mayer & Gallini, 1991, Mayer, Steinhoff, Bower & Mars, 1995). According to a **cognitive** theory of **multimedia** learning, students with high prior knowledge may be able to generate their own mental images while listening to an animation or reading a verbal text so having a contiguous visual presentation is not needed. Additionally, students who scored high on tests of spatial ability showed greater **multimedia** effects than did students who scored low on spatial ability (Mayer & Sims, 1994). According to a **cognitive** theory of **multimedia** learning, students with high spatial ability are able to hold the visual image in visual working memory and thus are more likely to benefit from contiguous presentation of words and pictures.

Coherence Principle: When giving a **multimedia** explanation, use few rather than many extraneous words and pictures. The fifth principle is that students learn better from a coherent summary which highlights the relevant words and pictures than from a longer version of the summary. For example, students who read a passage explaining the steps in how lightning forms along with corresponding illustrations generated 50% more useful solutions on a subsequent problem-solving transfer test than did students who read the same information with additional details inserted in the materials (Mayer, Bove, Bryman, Mars & Tapangco, 1996; Harp & Mayer, 1997). Sweller and his colleagues refer to this as the redundancy effect and

they have found a similar pattern of results (Bobis, Sweller & Cooper, 1993; Chandler & Sweller, 1991). This result is consistent with a **cognitive** theory of **multimedia** learning, in which a shorter presentation primes the learner to select relevant information and organize it productively.

By beginning with a theory of how learners process **multimedia** information, we have been able to conduct focused research that yields some preliminary principles of **multimedia** design. Although all of the principles are subject to further testing, this work demonstrates how it is possible to take a learner-centered approach to instructional technology. This work can be considered a success to the extent that this line of research contributes to the implementation of successful **multimedia** instruction.

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Note

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Figure Caption

Figure 1. A **cognitive** model of **multimedia** learning.