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Cognitive Theory and the Design of Multimedia Instruction

by William R. Robinson

"How should we design multimedia instructional messages in order to promote deep understanding in learners?" This is the leading question from the research program described in Richard Mayer's article "Cognitive Theory and the Design of Multimedia Instruction: An Example of the Two-Way Street Between Cognition and Instruction" *(1)*. Mayer and his coworkers create computer-based multimedia instructional materials involving animation and narration that present explanations of selected physical, mechanical, or biological systems. They test the effectiveness of these materials in promoting meaningful learning using transfer questions involving troubleshooting, redesigning, and deriving principles. For a presentation involving lightning, Mayer cites an example of a troubleshooting question as "Suppose you see clouds in the sky but no lightning. Why not?", an example redesigning question as "What could you do to decrease the intensity of lightning?", and an example of deriving principles as "What causes lightning?". Scoring several transfer questions provides information about the effectiveness of one multimedia presentation versus another.

Cognitive Theory and Multimedia Processing

Three theory-based assumptions about how people learn from words and pictures follow from cognitive theory: a dual channel assumption, a limited capacity assumption, and an active processing assumption.

The Dual Channel Assumption

The human cognitive system consists of two distinct channels for representing and manipulating knowledge: an auditory–verbal channel and a visual–pictorial channel *(2, 3)*. The auditory–verbal channel processes verbal representations of words that enter the cognitive system through the ears. The visual–pictorial channel processes pictorial representations of pictures that enter the cognitive system through the eyes.

The Limited Capacity Assumption

Working memory is the component of the human cognitive system that manipulates verbal and pictorial representations in the auditory–verbal and visual–pictorial channels. Working memory has a limited capacity for holding and manipulating information *(2, 4)*. Thus, the visual–pictorial channel can be overloaded if too many pictures (or other visual materials) are presented at one time. Similarly, the auditory–verbal channel can become overloaded if a large number of spoken words (or other sounds) are presented at one time. Overloading one channel can limit the processing ability of the other.

The Active Processing Assumption

Active processing within the auditory–verbal and visual–pictorial channels leads to meaningful learning. Active processing includes organizing relevant words and pictures into coherent pictorial and verbal models followed by integration with each other and with appropriate prior knowledge *(5, 6)*. These active learning processes are more likely to occur when working memory contains both pictorial and verbal representations at the same time.

The Cognitive Theory of Multimedia Learning

Pictures enter the cognitive system though the eyes. A learner attends to some aspects of the pictures, leading to the construction of a reduced set of images in working memory. In the cognitive process of organizing these images in working memory, the learner arranges selected images into a coherent mental representation called a pictorial model. This process of constructing knowledge by selecting, organizing, and integrating images is called *visuospatial thinking*. Spoken words enter the cognitive system through the ears. The learner attends to some of the words, leading to construction of word sounds in working memory. While organizing words, the learner arranges the selected words into a coherent mental representation called a verbal model. The processes of selecting, organizing, and integrating words is called *verbal thinking*. Integrating both pictures and words in working memory connects the pictorial model, the verbal model, and appropriate prior knowledge from long-term memory. According to the cognitive theory of multimedia learning, appropriate verbal and visuospatial thinking leads to meaningful learning.

Eight Principles of Multimedia Learning

Mayer presents eight principles for the design of multimedia that result from using the assumptions of the cognitive theory of multimedia learning (the Theory) to answer questions about the most effective design of multimedia. He also cites research[1] used to answer these questions.

Multimedia Principle

> Deeper learning occurs from words and pictures than from words alone.

This principle follows from answers to the question "Does adding pictures to a verbal explanation help learners to understand the explanation better?" According to the Theory, deeper understanding occurs when students mentally connect pictorial and verbal models of the explanation. This process is more likely to occur for multimedia presentations involving words and pictures than for presentations in words alone because multimedia presentations encourage parallel generation of both models. Mayer's results confirm the predictions of the Theory and are consistent with Rieber's finding *(7)* that students learn better from computer-based science lessons when animated graphics are included.

Contiguity Principle

Deeper learning results from presenting words and pictures simultaneously rather than successively.

Should words and pictures be presented simultaneously or should narration be presented before or after animation so a student spends twice as much time with the material? The Theory implies that simultaneous presentation would increase the opportunity for matching the pictures and words that need to be processed at the same time in order to facilitate construction of connections between them. This should result in deeper understanding. Mayer's research confirms this implication: Simultaneous presentation results in deeper learning than successive presentation.

Coherence Principle

Deeper learning occurs when extraneous words, sounds, or pictures are excluded rather than included.

How can we make multimedia presentations more interesting? One might presume that students learn more from a multimedia presentation that contains interesting asides (much as general chemistry texts contain material designed to catch the students' interest) than from a basic version containing no interesting asides. However, prior research shows that adding interesting but irrelevant text to a passage does not enhance learning and sometimes hinders it *(8)*. Similarly, the Theory suggests that adding interesting but irrelevant material to a multimedia presentation can overload one or both of the processing channels and disrupt the integration of pictorial models, verbal models, and prior knowledge. In his studies Mayer observed that students who received a basic version of a multimedia presentation (one without added words, sounds, or video) performed better on transfer tests than students who received an expanded version.

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Modality Principle

> Deeper learning occurs when words are presented as narration rather than as on-screen text.

The modality effect was first identified in a paper-based study *(9)* in which students learned to solve geometry problems more productively from printed illustrations and concurrent narration than from printed illustrations and printed text. For a multimedia presentation the Theory implies that use of on-screen text and animation could overload the visual channel while use of narration would free visual resources to attend to the animation. In a presentation with on-screen text, students need to attend to two different visual inputs, handicapping their ability to process both the words and the pictures. Mayer's research shows this appears to be the case: Students learn more deeply from animation and narration than from animation and on-screen text.

Redundancy Principle

> Deeper learning occurs when words are presented as narration rather than as both narration and on-screen text.

One suggestion for improving multimedia has been to present on-screen text along with animation and concurrent narration. Here again the Theory suggests that the added text will compete with the animation for cognitive resources in the visual–pictorial channel. Theory predicts that students learn more deeply from animation and narration than from animation, narration, and on-screen text. Mayer's results suggest students do learn more deeply from multimedia presentations consisting of animation and narration without on-screen text. His results are consistent with a version of the redundancy principle originally based on research with printed diagrams, speech, and printed text *(10, 11)*.

Interactivity Principle

> Deeper learning occurs when learners are allowed to control the presentation rate than when they are not.

Another theory-based recommendation for improving narrated animations is to allow learners to have some control over the presentation rate, for example, with a button with the words *Click here to continue*. According to the Theory, adding such user control can improve learning because it allows students to activate their cognitive processes at their own rates and reduce the chances of cognitive overload. Learners can take the time they need to build a visual image and coordinate it with the verbal explanation. In one study Mayer found that students performed better on a transfer test when an explanation of lightning formation was presented with student control rather than fixed form. However, he points out that additional studies are needed because prior research on learner control has led to inconclusive results *(13)*.

Signaling Principle

> Deeper learning occurs when key steps in the narration are signaled rather than nonsignaled.

Do signals incorporated into the narration help a learner recognize important ideas and their organization? Signaling can be accomplished by numbering key phrases (The first step is…, the second is…, etc.) or speaking important words in a deeper or louder voice. According to the Theory, if signaling directs the learner's attention to key events and the relations among them, this should enhance integration. In his one study Mayer found that students who received a signaled presentation performed better on a transfer test than did students who received a nonsignaled version; however, he believes additional research is needed to confirm this finding.

Personalization Principle

> Deeper learning occurs when words are presented in conversational style rather than formal style.

Will students try harder to understand a computer-based message if they feel that they are engaged in a social interaction? Will narration in a conversational style (adding personal comments and using first- and second-person rather third-person speech) improve learning? Although the Theory does not speak to these questions, Mayer's research shows that students perform better on transfer tests when the words were presented in conversational style rather than expository style. The personalization effect is also consistent with related findings reported by Reeves and Nass *(12)*.

Summary

Mayer's research program is directed towards two interconnected goals: "a theoretical goal of contributing to a cognitive theory of how people learn from words and pictures and a practical goal of contributing to the design of effective multimedia instruction for adults" *(1)*. Eight tentative principles of multimedia design, each based on cognitive theory and supported by the findings of empirical research, have resulted from this research. The work points out how cognitive science can inform instruction and how research in instruction can reinforce the theories of cognitive science.

Note

1. A complete set of references to Mayer's studies can be found in reference *1*.

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