Designing for Understanding: A Learner-Centered Approach to Multimedia Learning

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ABSTRACT
How can we help students understand scientific explanations of cause-and-effect systems, such as how lightning storms develop, or how the respiratory system works? One promising approach involves multimedia presentation of explanations in visual and verbal formats, such as presenting a computer-generated animation synchronized with narration or on-screen text. In this paper, a cognitive theory of multimedia learning is presented from which two principles of instructional design are derived and tested.

1. A COGNITIVE THEORY OF MULTIMEDIA LEARNING

The proposed cognitive theory of multimedia learning is based on the following assumptions: (a) working memory includes independent auditory and visual working memories (Baddeley, 1986); (b) each working memory store has a limited capacity (Sweller & Chandler, 1994); (c) meaningful learning occurs when a learner selects, organizes, and connects corresponding verbal and non-verbal information (Moreno & Mayer, 2000a; Paivio, 1986).

By beginning with a cognitive theory of how learners process multimedia information, we have been able to conduct focused research, which has yielded some preliminary principles of instructional design for multimedia explanations. To test the theory, we had college students watch a multimedia explanation about the process of lightning formation and studied their learning outcomes. We concentrated on three learning measures: recall of the steps involved in the process of lightning formation (retention test), matching of some frames of the animation with corresponding names (visual-verbal matching test), and using what was learned to solve new problems (problem solving transfer test).

2. THE MODALITY PRINCIPLE

How should verbal information be presented to students to enhance learning from animations: auditorily as speech or visually as on-screen text? In order to answer this question, Moreno and Mayer (1999) asked 137 college students to view an animation depicting the process of lightning in one of the following six conditions: with concurrent on-screen text (TT), with concurrent narration (NN), with narration preceding the corresponding portion of the animation (NA), with narration following the animation (AN), with on-screen text preceding the corresponding portion of the animation (TA), and with text following the animation (AT).

According to the cognitive theory of multimedia learning, students in group NN represent the animation in visual working memory and represent the corresponding narration in auditory working memory. Because they can hold corresponding pictorial and verbal representations in working memory at the same time, they are able to build referential connections between them. On the other hand, students in group TT need to represent both the animation and the on-screen text in visual working memory. As a consequence, visual working memory is likely to become overloaded. Therefore, a cognitive theory of multimedia learning predicts that students in group TT perform more poorly than students in group NN on the retention, matching, and transfer tests.

What happens when verbal and non-verbal information are presented sequentially rather than concurrently? Concurrent multimedia presentations force the learners to hold material from one source of information (verbal or non-verbal) in working memory before attending to the other source. Consequently, the narration group might have the advantage of being able to attend to both sources simultaneously. Thus, the next issue to test was if the advantage of narration over on-screen text resides in a modality principle. If this is the case, then the advantage for spoken explanations should not disappear when multimedia explanations are made sequential.

The results from the study showed that the text groups (TT, AT, and TA) scored significantly lower than the narration groups (NN, AN, and NA) in retention ($p < .001$), matching ($p < .005$), and problem solving transfer ($p < .001$). The findings replicate the modality effect found in prior studies on text and diagrams (Mousavi, Low, & Sweller, 1995), and allow us to infer the modality principle: Students learn better when the verbal information is presented auditorily as speech rather than visually as on-screen text both for concurrent and sequential presentations.

3. THE AUDITORY SPLIT-ATTENTION PRINCIPLE

Would entertaining adjuncts in the form of sounds or music help students' learning from a multimedia explanation? According to the cognitive theory of multimedia learning, learners process multimedia messages in their visual and auditory channels--both of which are limited in capacity. In the case of a narrated animation, the animation is processed in the visual channel and the narration is processed in the auditory channel. When additional auditory information is presented, it competes with the narration for limited processing capacity in the auditory channel. When processing capacity is used to process the music and sounds, there is less capacity available for paying attention to the narration, organizing it into a coherent cause-and-effect chain, and linking it with the incoming visual information. Based on this theory, we can predict that adding interesting music and sounds to a multimedia presentation will result in poorer performance on tests of retention, matching, and transfer. In order to test this prediction, Moreno and Mayer (2000b) asked 75 college students to view an animation depicting the process of lightning either with concurrent narration (Group N), with concurrent narration and environmental sounds (Group NE), with concurrent narration and music (Group NM), or with concurrent narration, environmental sounds and music (Group NEM).

The results showed that students scored significantly lower in both retention and transfer tests when music had been presented rather than when no music had been presented ($p < .0001$); but there was no significant difference between students who received environmental sounds and those who didn’t. There was a significant interaction between music and sounds ($p < .05$), in which the combination of music and environmental sounds (Group NEM) was particularly detrimental to retention and transfer performance. The mean matching scores for the four groups were not significantly different, with no main effect for music or sounds, and no significant interaction between music and environmental sounds. These findings suggest that adding auditory material that does not contribute to making the lesson intelligible can create auditory overload. The auditory split-attention principle can be inferred: Students learn better when extraneous auditory materials are excluded rather than included in multimedia explanations.

4. CONCLUSIONS

The present review demonstrates that presenting a multimedia explanation of how a system works does not insure students' understanding unless a learner-centered approach based on research principles is applied to the design. According to a cognitive theory of multimedia learning (Moreno & Mayer, 2000a), active learning occurs when a learner engages in the cognitive process of selecting relevant words and images, organizing words and images into coherent verbal and visual models, and integrating the corresponding components of the verbal and visual models. To foster the process of selecting, multimedia presentations should not contain too much extraneous information in the form of words or sounds. To foster the process of organizing, multimedia presentations should represent the steps in order and with clear signals for both the verbal and visual information. To foster the process of integrating, multimedia presentations should present words and pictures concurrently using modalities that effectively use available visual and auditory working memory resources. The major advance in our research program is to identify techniques for presentation of verbal and visual information that minimizes working memory load and promotes meaningful learning.

The most direct practical implication is clear: When designing multimedia learning environments (especially if visual and verbal information are presented simultaneously), present words auditorily rather than visually and do not add extraneous sounds unless relevant to the lesson's main message. A concise spoken multimedia explanation allows the learner to build a coherent mental representation--that is, to focus on the key elements and mentally organize them in a way that makes sense.

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