## 6

*When the relation between cognition and instruction is a two-way street, psychologists and educators communicate in ways that are mutually beneficial to both psychological theory and educational practice.*

# Cognitive Theory and the Design of Multimedia Instruction: An Example of the Two-Way Street Between Cognition and Instruction

*Richard E. Mayer*

There is an intertwined and reciprocal relation between cognitive theory and educational practice—a relation that benefits both fields. By *intertwined,* I mean that it is not possible to understand cognition fully without understanding how it works in realistic settings, such as how students learn and think in educational settings, and it is not possible to reform education appropriately without understanding how people learn and think. By *reciprocal* I mean that practical educational problems challenge psychologists to improve their cognitive theories, and educationally relevant cognitive theories challenge educators to improve their teaching practices. In this chapter, I explore a case example of the intertwined and reciprocal relation between cognition and instruction by focusing on how cognitive theories of

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learning can be used to enhance the learning of college students and other adults and how the challenges of higher education enhance the development of theories of how people learn.

## The Case of Multimedia Instructional Messages

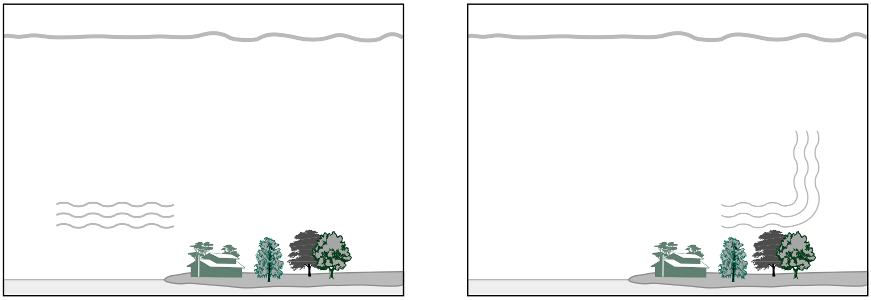
Consider the following scenario. A student who is studying weather sits down at a computer, opens an on-line encyclopedia, and clicks on an entry for "lightning." On the screen appears a 140-second animation depicting the steps in lightning formation, and through the speakers comes a corresponding narration describing the steps in the lightning formation. Figure 6.1 shows selected frames from the animation along with corresponding parts of the narration.

This is an example of a multimedia instructional message because instructional material is presented using words and pictures (narration and animation). I define multimedia instructional messages as presentations involving words (such as spoken or printed text) and pictures (such as animation, video, illustrations, and photographs) in which the goal is to promote learning.

How should we design multimedia instructional messages in order to promote deep understanding in learners? This has been the motivating question in our research program at the University of California, Santa Barbara (UCSB) for more than a decade. We began by selecting potentially meaningful material—mainly scientific explanations of how some physical, mechanical, or biological system works. Next, to create multimedia materials, we presented the explanations using animation and narration using a computer. Finally, to evaluate meaningful learning, we developed transfer questions, generally involving troubleshooting (for example, Suppose you see clouds in the sky but no lightning. Why not?), redesigning (for example, What could you do to decrease the intensity of lightning?), and deriving principles (for example, What causes lightning?). We allowed students two and a half minutes to write an answer to each transfer question, as they worked on one transfer question at a time. We scored the transfer questions by tallying the number of appropriate answers that the learner generated across a series of four or five transfer questions (for example, writing that there was no lightning because the top of the cloud was not above the freezing level or that negative particles had not fallen to the bottom of cloud).

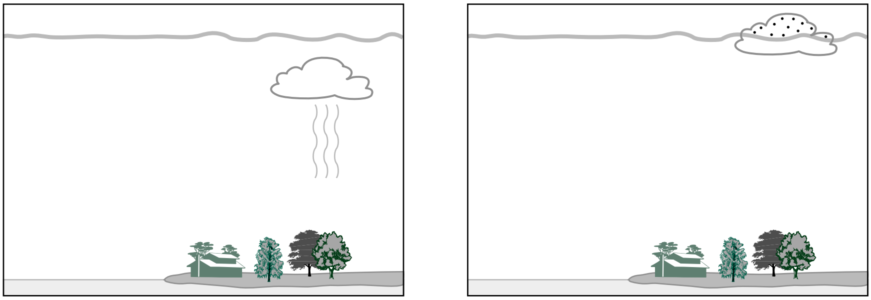
This chapter examines the design of multimedia learning environments as a case example of the intertwined and reciprocal relation between cognitive theory and educational practice. I first examine the contributions of cognitive theory to multimedia design issues and then the contributions of multimedia design issues to cognitive theory.

**Figure 6.1. Narration Script and Selected Frames from Animation on Lightning**



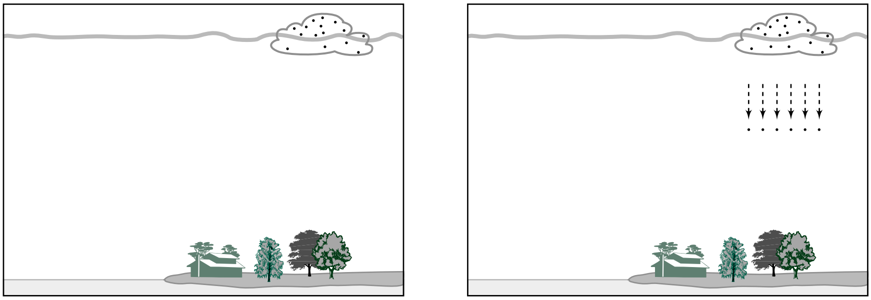
"Cool moist air moves over a warmer surface and becomes heated."

"Warmed moist air near the earth's surface rises rapidly."



"As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud."

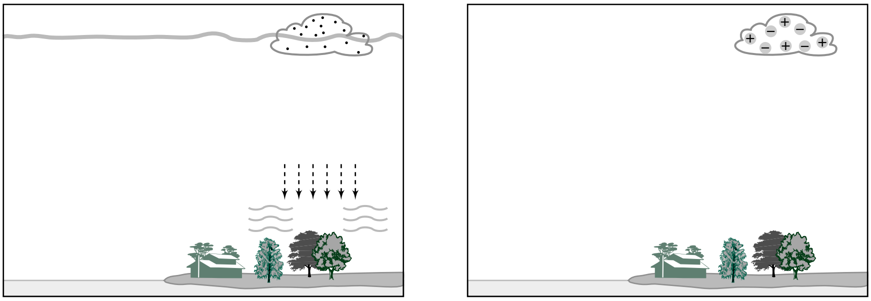
"The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny ice crystals."



"Eventually, the water droplets and ice crystals become too large to be suspended by the updrafts."

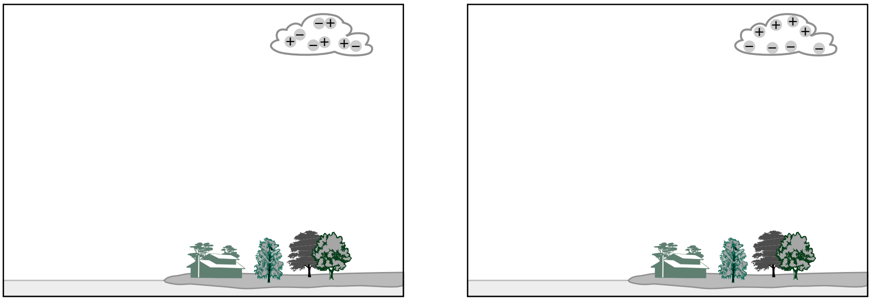
"As raindrops and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts."

**Figure 6.1.** *(continued)*



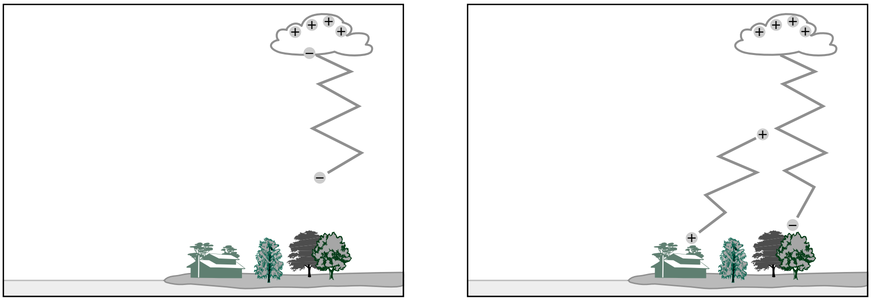
"When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind people feel just before the start of the rain."

"Within the cloud, the rising and falling air currents cause electrical charges to build."



"The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice."

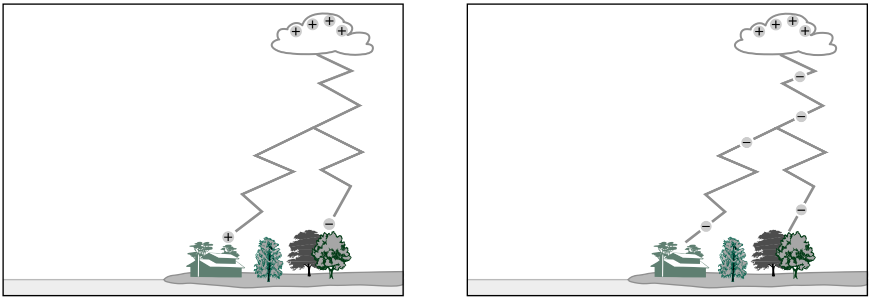
"The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top."



"A stepped leader of negative charges moves downward in a series of steps. It nears the ground."

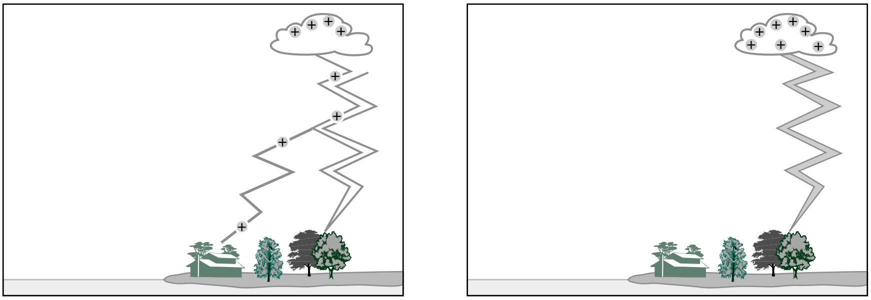
"A positively charged leader travels up from such objects as trees and buildings."

**Figure 6.1.** *(continued)*



"The two leaders generally meet about 165 feet above the ground."

"Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright."



"As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path."

"This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning."

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## The Relation Between Cognition and Instruction

I have previously described a progression of three relations between cognition and instruction (Mayer, 1999)—a one-way street, a dead-end street, and a two-way street—and here will explore just the last of these.

When the relation between cognition and instruction is a two-way street, psychologists and educators communicate in ways that are mutually beneficial to both psychological theory and educational practice. The relation is intertwined and reciprocal: psychologists seek to develop research-based theories of learning that are relevant to practical educational problems, and educators offer realistic venues for testing cognitive theories of learning. This vision has gained some acceptance in psychology and education throughout the latter portion of the twentieth century and offers great potential for the new century (Mayer, 1999).

## How Cognitive Theory Contributes to Suggestions for Multimedia Design Principles

Cognitive theory offers three theory-based assumptions about how people learn from words and pictures: the dual channel assumption, the limited capacity assumption, and the active processing assumption.

**Dual Channel Assumption.** First, the human cognitive system consists of two distinct channels for representing and manipulating knowledge: a visual-pictorial channel and an auditory-verbal channel (Baddeley, 1986, 1999; Paivio, 1986). Pictures enter the cognitive system through the eyes and may be processed as pictorial representations in the visual-pictorial channel. Spoken words enter the cognitive system through the ears and may be processed as verbal representations in the auditory-verbal channel.

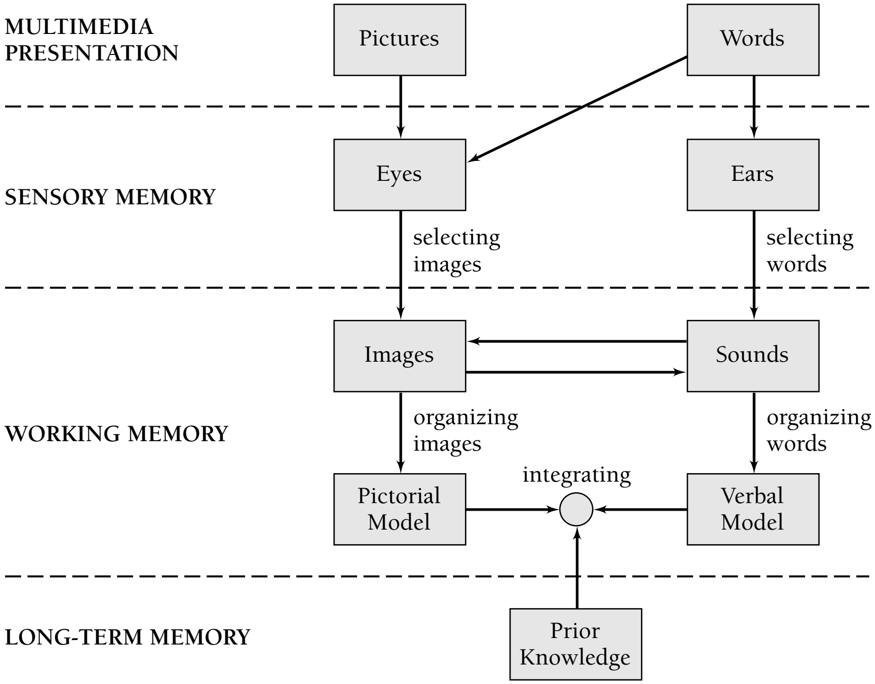
**Limited Capacity Assumption.** Each channel in the human cognitive system has a limited capacity for holding and manipulating knowledge (Baddeley, 1986, 1999; Sweller, 1999). When a lot of pictures (or other visual materials) are presented at one time, the visual-pictorial channel can become overloaded. When a lot of spoken words (and other sounds) are presented at one time, the auditory-verbal channel can become overloaded.

**Active Processing Assumption.** Meaningful learning occurs when learners engage in active processing within the channels, including selecting relevant words and pictures, organizing them into coherent pictorial and verbal models, and integrating them with each other and appropriate prior knowledge (Mayer, 1999, 2001; Wittrock, 1989). These active learning processes are more likely to occur when corresponding verbal and pictorial representations are in working memory at the same time.

## A Cognitive Theory of Multimedia Learning

Figure 6.2 presents a cognitive theory of multimedia learning based on these three basic ideas about how the human mind works. The right column of the figure represents the auditory-verbal channel and the left column the visual-pictorial channel. Words enter the cognitive system through the ears (if the words are spoken), and pictures enter though the eyes. In the cognitive process of selecting words, the learner pays attention to some of the words, yielding the construction of some word sounds in working memory. In the cognitive process of selecting images, the learner pays attention to some aspects of the pictures, yielding the construction of some images in working memory. In the cognitive process of organizing words, the learner mentally arranges the selected words into a coherent mental representation in working memory that we call a verbal model. In the cognitive process of organizing images, the learner mentally arranges the selected images into a coherent mental representation in working memory that we call a pictorial model. In the cognitive process of integrating, the learner mentally connects

**Figure 6.2. Cognitive Theory of Multimedia Learning**



*Source:* Reprinted from Figure 3-2 in Mayer (2001). Copyright © 2001 by Cambridge University Press. Reprinted with permission.

the verbal and pictorial models, as well as appropriate prior knowledge from long-term memory.

Visuospatial thinking is involved in this process of knowledge construction mainly through the processes of selecting images, organizing images, and integrating. Verbal thinking is involved through the processes of selecting words, organizing words, and integrating. According to the cognitive theory of multimedia learning, meaningful learning occurs when learners engage in appropriate verbal and visuospatial thinking, as indicated by all of the cognitive processes summarized in Figure 6.2.

In education, verbal modes of instruction have traditionally played a larger role than pictorial modes of instruction. Verbal modes of instruction are based on words and include spoken text (such as lectures and discussions) and printed text (such as the text portion of textbooks or on-screen text). Pictorial modes of instruction are based on pictures and include static graphics (such as photographs, illustrations, figures, and charts) and dynamic graphics (such as animation and video). In spite of the disproportionate emphasis on verbal forms of instruction, advances in computer graphics and the proliferation of pictorial representations on the World Wide Web have led to an increasing interest in exploiting the potential of pictorial forms of instruction as aids to meaningful learning (Pailliotet and Mosenthal, 2000). In the research presented next, I examine how adding visual modes of instruction to verbal ones can result in deeper understanding in learners. In particular, I explore the conditions under which multimedia explanations prime the verbal and visuospatial thinking required for meaningful learning.

## How Design Principles Contribute to Testing of Cognitive Theory

Can the cognitive theory of multimedia learning stand up to rigorous testing in the real world of multimedia instructional design? Educational venues offer important opportunities for testing cognitive theories such the one summarized in Figure 6.2. In this section, I examine eight predictions—some of which conflict with common sense—that can be derived from the cognitive theory of multimedia learning. I also summarize research that seeks to test these predictions and the cognitive theory of multimedia learning from which they are derived.

**Multimedia Principle.** Does adding pictures to a verbal explanation help learners to understand the explanation better? For example, a verbal explanation of how lightning storms develop could consist of the narration given in Figure 6.1, whereas a multimedia explanation could consist of the narration along with the animation shown in that figure. In both cases, students hear the same verbal explanation, but the students who receive a multimedia explanation also see a concurrent animation depicting the steps in lightning formation.

According to a commonsense view, the words and pictures both convey the same information, so the information provided by adding the animation is redundant. Thus, students who receive the verbal explanation in the form of narration should perform as well on the transfer test as students who receive the multimedia explanation in the form of narration and concurrent animation.

The commonsense view conflicts with the cognitive theory of multimedia learning—in particular, with the idea that carefully crafted words and pictures can enhance the learner's understanding of an explanation. The multimedia presentation encourages the learner to build a pictorial mental model of the lightning system and to connect it mentally with a verbal mental model of the lightning system. According to the cognitive theory of multimedia learning, deeper understanding occurs when students mentally connect pictorial and verbal representations of the explanation. This process is more likely to occur for multimedia presentations than for presentations in words alone.

Students learn more deeply from a multimedia explanation than from a verbal explanation, as shown in three studies in which students viewed a narrated animation about pumps or brakes or simply listened to a narration (Mayer and Anderson, 1991, experiment 2a; Mayer and Anderson, 1992, experiments 1 and 2). In each of three studies, students scored substantially higher on the transfer test when they received a multimedia explanation rather than a verbal explanation. The median effect size was 1.90. These results point to the importance of pictorial representations in helping learners to understand explanations and allow us to offer the multimedia principle: Students learn more deeply from multimedia presentations involving words and pictures than from words alone. This principle is summarized in Table 6.1 (as are the other principles). The multimedia principle is also consistent with Rieber's finding (1990) that students learn better from computer-based science lessons when animated graphics are included.

**Contiguity Principle.** How should words and pictures be coordinated in multimedia presentations? For example, consider a narrated animation that explains how lightning storms develop, as summarized in Figure 6.1. In the narrated animation, corresponding words and pictures are presented simultaneously so that, for example, when the narration says, "Negatively charged particles fall to the bottom of the cloud," the animation shows negative signs moving to the bottom of the cloud. In contrast, consider a situation in which the entire narration is presented before or after the entire animation so that the narration and animation are presented successively.

**Table 6.1. Principles of Multimedia Learning Based on a Cognitive Theory of Multimedia Learning**

| *Principle* | *Number of Tests* | *Effect Size* |
|---|---|---|
| 1. Multimedia principle: Deeper learning from words and pictures than from words alone | 3 of 3 | 1.90 |
| 2. Contiguity principle: Deeper learning from presenting words and pictures simultaneously rather than successively | 8 of 8 | 1.30 |
| 3. Coherence principle: Deeper learning when extraneous words, sounds, or pictures are excluded rather than included | 4 of 4 | 0.82 |
| 4. Modality principle: Deeper learning when words are presented as narration rather than as on-screen text | 4 of 4 | 1.17 |
| 5. Redundancy principle: Deeper learning when words are presented as narration rather than as both narration and on-screen text | 2 of 2 | 1.24 |
| 6. Personalization principle: Deeper learning when words are presented in conversational style rather than formal style | 2 of 2 | 0.82 |
| 7. Interactivity principle: Deeper learning when learners are allowed to control the presentation rate than when they are not | 1 of 0.97 | |
| 8. Signaling principle: Deeper learning when key steps in the narration are signaled rather than nonsignaled | 1 of 1 | 0.74 |

At first glance, it might appear that successive presentation would promote learning as well as or even better than simultaneous presentation. In both presentations, the learner receives exactly the same narration and animation, so you might expect both presentations to produce equivalent levels of learning. Learners exposed to the successive presentation spend twice as much time as students in the simultaneous presentation, so you might even expect the successive presentation to produce better learning than the simultaneous presentation. However, according to the cognitive theory of multimedia learning, students are more likely to engage in productive cognitive processing when corresponding words and pictures are presented at the same time. Simultaneous presentation increases the chances that corresponding words and pictures will be in working memory at the same time, thereby enabling the learner to construct mental connections between them. This cognitive processing, which depends on the learner's integrating of verbal and pictorial representations, should result in deeper understanding as reflected in measures of problem-solving transfer.

Simultaneous presentation results in deeper learning than successive presentation, as shown by eight studies in which students viewed a narrated animation about lightning, brakes, pumps, or lungs in which the animation and narration were simultaneous or successive (Mayer and Anderson, 1991, experiments 1 and 2a; Mayer and Anderson, 1992, experiments 1 and 2; Mayer and Sims, 1994, experiments 1 and 2; Mayer, Moreno, Boire, and Vagge, 1999, experiments 1 and 2). In each of the eight studies, students who received the simultaneous presentation performed better on tests of problem-solving transfer than did students who received the successive presentation. The median effect size was 1.30.

Based on these results, there is another condition that promotes meaningful learning, which I call the contiguity principle: Students learn more deeply from multimedia presentations in which animation and narration are presented simultaneously rather than successively (see Table 6.1). The contiguity principle is also consistent with research by Baggett and colleagues (Baggett, 1984, 1989; Baggett and Ehrenfeucht, 1983) showing that students learn an assembly procedure better when corresponding narration and film are presented simultaneously than when they are separated in time.

**Coherence Principle.** How can we make multimedia presentations more interesting? Again, consider a narrated animation that explains how lightning storms develop, as summarized in Figure 6.1. To spice up this lesson, we could insert a few short video clips showing severe lightning storms or what happened when a golfer was struck by lightning. Alternatively, we could add background music and environmental sounds, such as the sound of wind blowing. We could even insert some additional narration such as a brief story about a football player's experience of being struck by lightning or what happens when lightning strikes an airplane in flight. The rationale for adding these interesting adjuncts is that they will motivate the learner to exert more effort to understand the narrated animation. This rationale is based on interest theory: the idea that adding interesting adjuncts arouses the learner, and this arousal results in increased attention to the incoming material (Harp and Mayer, 1997, 1998).

This seemingly reasonable interest theory of learning posits that students learn more from an expanded version of a multimedia presentation (one containing interesting adjuncts) than from a basic version (one containing no interesting adjuncts). However, Dewey (1913) was the first educational thinker to warn against viewing interest as some sort of flavoring that could be sprinkled on an otherwise boring lesson. Overall, research on seductive details shows that adding interesting but irrelevant text to a passage does not enhance learning of the passage and sometimes actually hinders learning (Renninger, Hidi, and Krapp, 1992). According to the cognitive theory of multimedia learning, adding interesting but irrelevant material to a multimedia presentation can overload one of the channels and thereby disrupt the process of making sense of the explanation in several ways. For example, adding video clips can cause the learner to pay attention to the sensational material in the video clips rather than to the causal explanation in the animation, inserting video clips can disrupt the process of building a causal chain because the video separates steps in the chain, and learners may use the content of the video clips as an assimilative context encouraging them to relate all the material to the theme of lightning dangers.

Whether students learn more deeply from a basic version than an expanded version of a multimedia presentation was addressed in four studies in which they viewed a multimedia presentation about lightning or brakes that either did or did not include additional words, sounds, or video (Mayer, Heiser, and Lonn, 2001, experiments 1 and 3; Moreno and Mayer, 2000, experiments 1 and 2). For example, in the presentation about lightning, additional words included descriptions of events in which a person was struck by lightning, additional sounds included background instrumental music or sounds of lightning storms, and additional video included short video clips of lightning storms. In each of the four studies, students who received the basic version (without added words, sounds, or video) performed better on tests of problem-solving transfer than did students who received the expanded version. The median effect size was 0.82.

Based on these results, the coherence principle can be proposed: Students learn more deeply from multimedia presentations in which extraneous words, sounds, and video are excluded rather than included (see Table 6.1). In related research, Kozma (1991) reports that audio portions of a television presentation can attract people's attention momentarily to various irrelevant features of the images on the screen.

**Modality Principle.** So far, our research shows that meaningful learning is fostered by concise animated narrations. When sound is not readily available, it might make sense to present the narration as on-screen text. In this way, students receive both words (as on-screen text) and pictures (as animation), and the words are presented concurrently with the corresponding portions of the animation. Common sense tells us that words mean the same thing whether they are presented as narration or as on-screen text, so it is harmless to change narration to on-screen text in multimedia explanations. However, according to the cognitive theory of multimedia learning, the visual channel can become overloaded when learners must use their visual cognitive resources both to read the on-screen text and watch the animation. In contrast, when words are presented as narration, they are processed in the auditory channel, which frees the visual channel to focus on processing the animation.

Students learn more deeply from animation and narration than from animation and on-screen text, as shown in four studies involving multimedia explanations of lightning formation or how brakes work. Students performed better on transfer tests when the multimedia presentation consisted of animation and narration than animation and on-screen text (Mayer and Moreno, 1998, experiments 1 and 2; Moreno and Mayer, 1999, experiments 1 and 2). The median effect size was 1.17.

These results highlight the modality principle: Students learn more deeply from animation and narration than from animation and on-screen text (see Table 6.1). The modality effect was first identified in a paper-based environment by Mousavi, Low, and Sweller (1995); students learned to solve geometry problems more productively from printed illustrations and concurrent narration than from printed illustrations and printed text.

**Redundancy Principle.** Another suggestion for improving a multimedia presentation is to present animation along with concurrent narration and on-screen text. The rationale for presenting the same words in two formats is that students will be able to choose the format that better suits their learning style. If students learn better from spoken words, they can pay attention to the narration; if they learn better from printed words, they can pay attention to the on-screen text. In short, adding on-screen text to a narrated animation can be justified on the commonsense grounds that it accommodates individual learning styles better. However, the cognitive theory of multimedia learning suggests that the added on-screen text will compete with the animation for cognitive resources in the visual-pictorial channel, creating what Sweller (1999) calls a split-attention effect. In short, students will have to pay attention visually to both the printed words and the animation, resulting in a detriment to their processing of both the words and pictures. Thus, the cognitive theory of multimedia learning predicts that students learn more deeply from animation and narration than from animation, narration, and on-screen text.

To test this prediction, my colleagues and I conducted two comparisons in which students learned about lightning formation from animation and narration or from animation, narration, and on-screen text (Mayer, Heiser, and Lonn, 2001, experiments 1 and 2). In both studies, students who received animation and narration performed better on transfer tests than did students who received animation, narration, and on-screen text. The median effect size was 1.24.

These results suggest another condition that promotes meaningful learning, which can be called the redundancy principle: Students learn more deeply from multimedia presentations consisting of animation and narration than from animation, narration, and on-screen text (see Table 6.1). It is a somewhat more restricted version of the redundancy principle originally proposed by Kalyuga, Chandler, and Sweller (1999) and by Sweller (1999) based on research with printed diagrams, speech, and printed text.

**Personalization Principle.** In the previous sections, our various attempts to improve on animated narrations failed: learning was hurt when we increased the presentation time by presenting the animation and narration successively, added interesting adjunct material such as interspersed video clips, changed the narration to on-screen text, or added on-screen text. Undaunted, we continue to search for improvements and now focus on improvements that are consistent with the cognitive theory of multimedia learning.

Returning to the issue of how to increase students' interest and motivation so that they will try hard to make sense of the material, perhaps students will try harder to understand a computer-based message if they feel that they are engaged in a social interaction (Reeves and Nass, 1996). Thus, a potentially useful recommendation is to add a conversational style to the narration in a multimedia explanation, such as adding personal comments and using first- and second-person rather third-person constructions.

Whether students learn more deeply from a personalized version than a nonpersonalized version of a multimedia presentation was addressed in two studies in which students viewed a multimedia presentation about lightning that included either personalized or nonpersonalized prose (Moreno and Mayer, 2000, experiments 1 and 2). For example, the first segment in the personalized version included the addition, "Congratulations! You have just witnessed the birth of your own cloud." As another example, in the second segment, the sentence, "The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny ice crystals" was changed to "Your cloud's top extends above the freezing level, so the upper portion of your cloud is composed of tiny ice crystals." Overall, in two out of two studies, students performed better on transfer tests when the words were presented in conversational style rather than expository style. The median effect size was 1.30.

This result allows us to offer another condition that promotes meaningful learning, which can be called the personalization effect: Students learn more deeply when words are presented in a conversational style than in an expository style (see Table 6.1) and is consistent with related findings reported by Reeves and Nass (1996).

**Interactivity Principle.** Another theory-based recommendation for improving on narrated animations is to allow learners to have some control over the presentation rate. For example, the lightning passage consists of sixteen segments; each segment lasts about ten seconds and contains a sentence and animation clip that depicts one major change. To give learners more control, we added a button in the lower right corner with the words, "Click here to continue." When the learner clicked on the button, the next segment was presented, consisting of about ten seconds of narrated animation. In this way, learners could receive the entire presentation, segment by segment, at their own rates.

According to the cognitive theory of multimedia learning, adding simple user interactivity can improve learning because it reduces the chances of cognitive overload and encourages learners to engage in each of the cognitive processes summarized in Figure 6.2. At the end of each segment, learners can take all the time they need to build a visual image and coordinate it with the verbal explanation.

As predicted, in our one study testing this issue, students performed better on a transfer test when an explanation of lightning formation was presented in interactive form rather than fixed form (Mayer and Chandler, 2001, experiment 2). The effect size was 0.97. Additional studies are needed to confirm this finding.

This research offers preliminary evidence consistent with a possible new condition for promoting meaningful learning, which we call the interactivity principle: Students learn more deeply when they can control the presentation rate of multimedia explanations than when they cannot (see Table 6.1). Prior research on learner control has led to inconclusive results, attributable to "the lack of theoretical foundations undergirding the experiments" (Williams, 1996, p. 963).

**Signaling Principle.** The final theory-based recommendation for improving on narrated animations is incorporating signals into the narration that help the learner determine the important ideas and how they are organized. For example, consider a narrated animation explaining how airplanes achieve lift, including the ideas that the top of the wing is more curved than the bottom, air has more distance to travel across the top than across the bottom, and air pressure is less on top than on the bottom of the wing. In addition to the normal version of this multimedia presentation, we can create a signaled version that includes the following:

An introductory outline of the main steps in lift including the phrases beginning with *first, second,* and *third*
Headings spoken in a deeper voice and keyed to these steps, such as "Wing shape: Curved upper surface is longer" or "Air flow: Air moves faster across top of wing" or "Air pressure: Pressure on the top is less"
Pointer words aimed at showing the causal links among the steps, such as "because it's curved . . . "
Highlighted words spoken in a louder voice, such as emphasizing *top,*

*longer,* and *bottom* in the sentence, "The surface of the top of wing is longer than on the bottom."

The signaling does not add any new words to the passage, but rather emphasizes the three key steps in achieving lift and the causal relations among them.

According to a cognitive theory of multimedia learning, signaling can help guide the process of making sense of the passage by directing the learner's attention to key events and the causal relations among them. Although the signaling is verbal, it can also guide visuospatial thinking by helping the learner construct mental images that correspond to the key ideas (such as the top of the wing being longer than the bottom).

Do students learn more deeply from signaled than nonsignaled presentations? In the one study in which we tested this issue, students who received a signaled presentation on how airplanes achieve lift performed better on a transfer test than did students who received a nonsignaled version (Mautone and Mayer, 2001, experiment 3). The effect size was 0.74. Additional research is needed to confirm this finding. Based on these results we tentatively propose another condition that fosters meaningful learning, which we call the signaling principle: Students learn more deeply when multimedia explanations are signaled rather than nonsignaled (see Table 6.1). Prior research focused mainly on signaling of printed text (Lorch, 1989; Loman and Mayer, 1983).

## The Future of Cognition and Instruction

Overall, our research program on multimedia learning has been driven by two mutually reinforcing 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. The result has been the discovery of eight tentative principles of multimedia design, each based on cognitive theory and supported by the findings of empirical research. Although each principle of multimedia design is subject to limitations and certainly needs additional research, this review points to the progress that can be made when there is a two-way street between cognitive science and instruction. This makes it easy to envisage a future in which the mutually beneficial relation between cognitive theory and educational practice continues to flourish.

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