CHAPTER 4

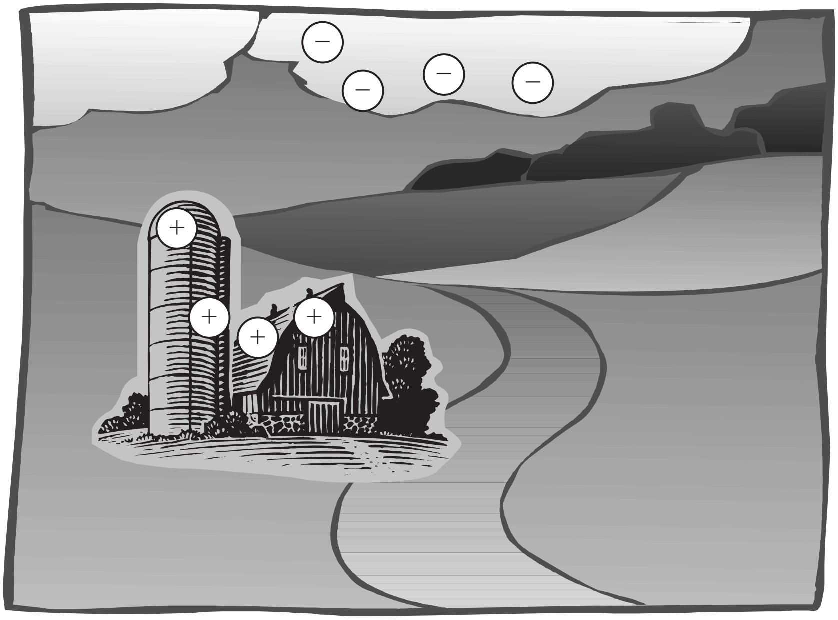
Graphics and Learning

Graphics are only effective to the extent that they support rather than disrupt psychological events of learning. To lay the groundwork for Section Two, in this chapter we overview the psychological processes that underpin learning. We look at the differences and relationships between the two memory siblings involved in learning: working memory and long-term memory. We then overview the six important instructional events that help learners transform content in the training environment into new knowledge and skills in long-term memory. These six events provide a basis for many recommendations on the best design of visuals. We conclude with a summary of six guidelines for selection and design of instructional graphics based on their psychological functions.

NOT ALL GRAPHICS ARE EQUAL

When it comes to learning, not all visuals are equally effective. Graphics that illustrate an instructional text can improve learning. However, different graphics used to illustrate that same text can depress learning. Mayer (2009) compared learning from eleven different lessons that used text alone to lessons that added visuals to the text. The topics included how brakes, pumps, and lightning work. He found that individuals who studied from lessons that included illustrations such as the one shown in Figure 4.1 learned significantly more than those who studied the same lessons without illustrations. The median effect size from all eleven experiments was 1.39, which is a large improvement. Effect sizes over 1.0 suggest that the results should be considered for implementation by practitioners.

Figure 4.1. An Interpretive Illustration from a Lesson on Lightning Formation.



Lightning results from the difference in electrical charges
between cloud and ground.

Adapted from Harp and Mayer, 1998.

In contrast, in other research using the same lesson content, Mayer (2009) found that visuals such as the one shown in Figure 4.2 actually depressed learning! Individuals who studied lessons that *omitted these extraneous visuals* learned much more. In six different experiments, lessons *without extraneous visuals* resulted in a median effect size improvement of 1.66, which is very high. Together these experiments show us that visuals are a powerful instructional method and their effects can be huge—for better or for worse!

GRAPHICS AND LEARNING

The reasons for the different effects of lesson graphics lie in how they interact with the brain. In order to use visuals to improve learning and performance, you need to select and design them based on how they help or hinder psychological learning

Figure 4.2. An Extraneous Illustration from a Lesson on Lightning Formation.

Metal airplanes conduct lightning very well, but they sustain little damage because the bolt passes right through.

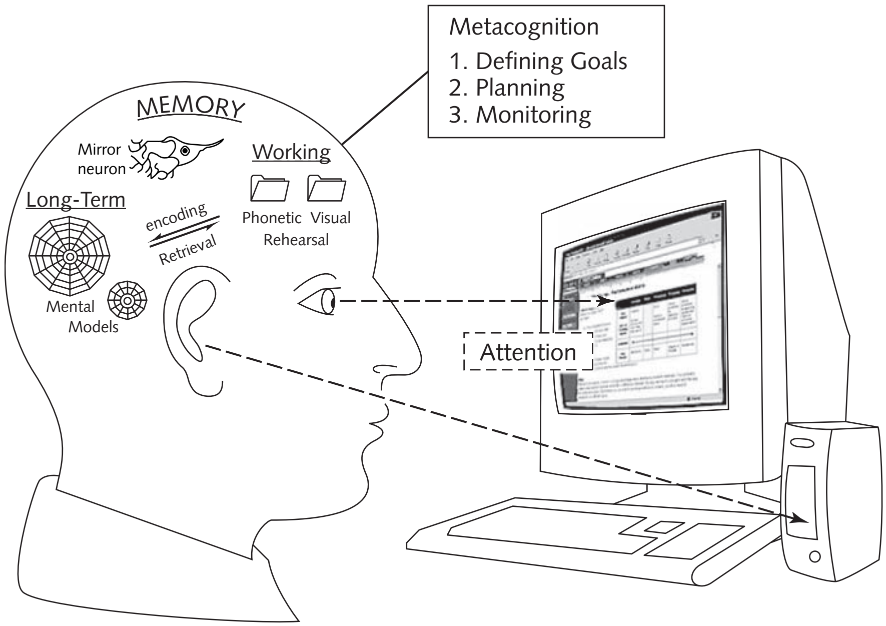
Adapted from Harp and Mayer, 1998.

processes. In this chapter we will overview the major processes involved in human learning and summarize the most recent ideas on how visuals can improve processing of information. In the chapters that follow this one, we describe and illustrate how best to use visuals to support each psychological event overviewed here.

A TALE OF TWO MEMORIES

When planning any training event, you will need to consider the two complementary memory systems illustrated in Figure 4.3—working memory (WM) and long-term memory (LTM). These memory systems have quite different characteristics regarding: (1) their capacities, (2) longevity of stored information, and (3) abilities to process information. First, working memory has a very limited capacity for information, whereas long-term memory contains a vast repository of stored knowledge. The expression "7 +/− 2" refers to the limited number of "chunks"

Figure 4.3. Human Learning Processes.

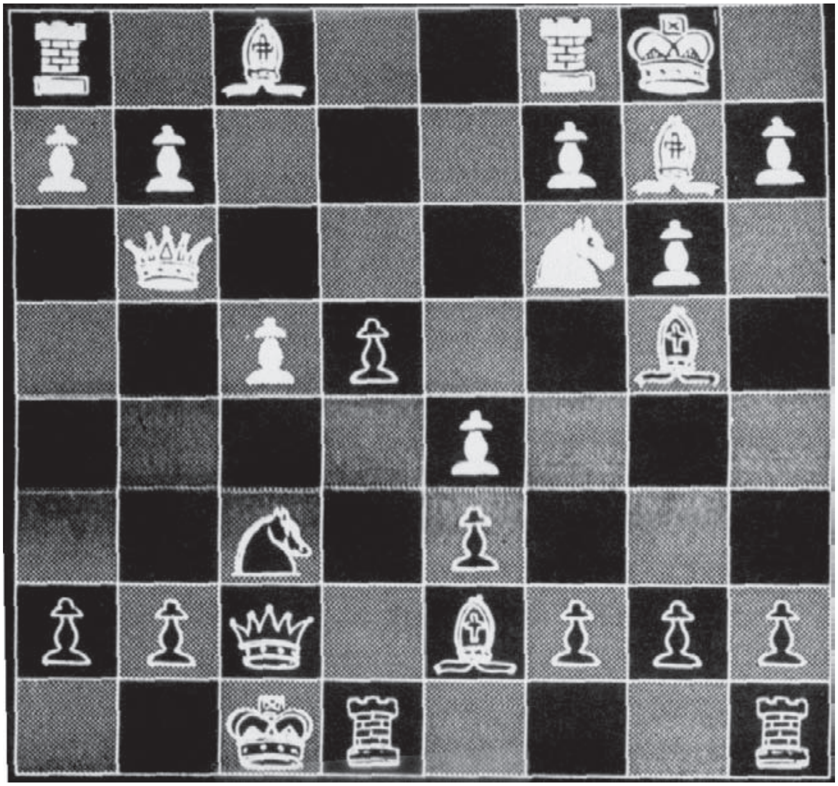


of information that working memory can hold at one time. Second, while information entering working memory will have a short shelf life unless kept active, knowledge in long-term memory lasts indefinitely. Thus the storage capacity of working memory is very limited both in size and duration of information compared to long-term memory. However, it is in working memory that active mental work, including learning, takes place. Working memory is the site of conscious thought and processing, while long-term memory is a relatively inert repository of our knowledge and memories.

Long-Term Memory Influences the Capacity of Working Memory

While these memory siblings are very different, they work together in complementary ways. Although working memory can hold only a few items of information at a time, its virtual capacity is influenced by knowledge already stored in LTM. For example, look at the chess board diagrammed in Figure 4.4.

Figure 4.4. A Mid-Play Chess Board.



How many times would you need to refer back to this board in order to accurately reconstruct it from memory? A now-famous experiment compared the number of times master and novice chess players referred back to the board in order to reconstruct it accurately. Not surprisingly, novices needed to look back many more times than did master-level players. However, now the experiment gets interesting! In part two, the memories of experts and novices for board positions were tested again. But this time, the pieces were placed *randomly on the board*. How would a meaningless board affect memory of the experts and the novices? Unexpectedly, the experts now actually required more times to review the board than did the novices! The novices needed about the same number of referrals back to the random board that they needed when working with the mid-play board (Chase & Simon, 1973).

The collapse of the master chess player's memory for a random board reveals the unique relationship between WM and LTM. For a novice player each chess piece represents a chunk of information no matter how it is placed on the board. An expert, however, looks at the board for familiar play patterns made up of clusters of four or five individual pieces. The expert player is estimated to have over 50,000 such mid-play patterns resident in LTM (Simon & Gilmartin, 1973). This allows the expert to handle much larger chunks in WM than novices. Therefore, the mid-play board shown in Figure 4.4 includes twenty-four chunks for a novice (one for each piece). However, that same board includes approximately nine to twelve chunks for an expert player.

In summary, the more related knowledge about a domain that is stored in LTM, the larger is the virtual capacity of WM. That's because stored knowledge in LTM supports larger chunks in WM. However, in instructional settings most students are relatively novice. Therefore, they will only be able to handle a few chunks of information at a time before they become overloaded. Since we need free working memory capacity for learning, effective instruction must minimize memory overload.

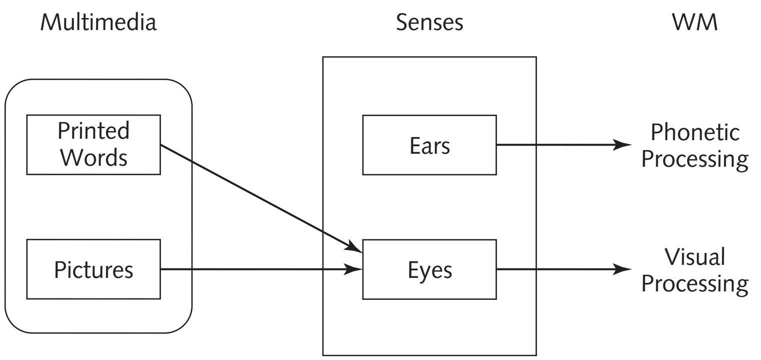
UNIQUE BRAIN STORAGE FOR VISUAL INFORMATION

For a long time, WM was assumed to be a limited capacity active processor that was more or less homogeneous. However, recent research reveals subcomponents of working memory with different roles. Two major subcomponents are illustrated in the visual and phonetic folders in Figure 4.3. One of the subcomponents stores and processes visual information, while the phonetic component stores and processes auditory information. As we will see, these subcomponents have important consequences for how to best display visuals and words for learning.

Divide Content Across the Visual and Auditory Centers

For learning purposes, we can maximize the limited resources available in WM by effectively using both the auditory and the visual subsystems. If a graphic is explained by words presented in audio, learning of complex new information is better than if the same graphic is explained by words presented in text. As shown in Figure 4.5, a graphic and the on-screen text describing it both require resources of the visual subsystem which becomes overloaded. However, if a graphic is explained by words presented in audio, then the processing load is shared between the visual and auditory subsystems. We will discuss additional techniques for use of graphics to manage mental load in Chapter 7.

Figure 4.5. Printed Words and Graphics Both Enter the Visual Processing Centers of WM.



With permission from Clark and Mayer, 2008.

The Mirror Neuron System

In the 1990s a specialized set of nerves in the brain called the *mirror neuron system* was discovered in monkeys. Using brain probes, researchers accidentally discovered that the same neurons that were activated when the monkey grasped an object were also activated when the monkey observed a human grasp an object. The mirror neuron system is the basis for observational learning. When we watch another person perform some task involving motion, for example, folding origami or performing surgery, the mirror neuron system kicks in. It records the activity and stimulates imitation.

We mentioned in Chapter 1 that animations are better than still visuals to teach motion skills but not to build conceptual understanding. The reason for this dichotomy lies in the mirror neuron system that has evolved to support learning by observation and imitation. Although animations are complex visuals that could easily overload working memory, animations that depict motor skills apparently bypass working memory by way of the mirror neuron system (van Gog, Paas, Marcus, Ayres, & Sweller, 2009). Just as you may want to use audio to describe visuals to take advantage of the visual and auditory subsystems in working memory, so might you use animations that leverage the mirror neuron system to depict procedures that involve motion.

HOW LEARNING HAPPENS

Ultimately new knowledge from the learning environment is actively integrated into existing knowledge in LTM in a way that it can readily be accessed after training when needed on the job. As illustrated in Figure 4.3, effective instructional methods, including graphics, support the following psychological learning processes.

Directing Attention

New content in the training materials must be actively attended in order to enter working memory. We have all had the experience of being in a conversation and realizing we did not hear what the speaker said. Too late we realize our attention was directed elsewhere. Attention management is important because working memory capacity is so limited that it can only actively process extremely limited amounts of information. Where you direct your attention, your working memory capacity is used and other unattended information in your internal or external environment is missed.

Because almost any visual will attract attention, it's important that you use visuals in ways that direct learners toward the instructional goals rather than distract them with unrelated themes or content. In addition, in a complex visual, you need to focus attention to the relevant parts using some type of visual signal such as color or a circle.

Awakening Appropriate Prior Knowledge

During learning, new information comes into working memory from the lesson and must be integrated into existing knowledge already in LTM. Therefore, knowledge stored in LTM that is relevant to the new content must be brought into WM where the integration takes place. Psychologists call this process "*activation of prior knowledge.*" For example, suppose you are teaching novices how to use a word processing program to edit online documents. Even computer novices will be familiar with the idea of cutting out words, copying words, and pasting them into different locations in a paper manuscript. Activating these editing concepts early in the lesson will help them acquire the new online editing skills.

An appropriate visual can help learners activate prior knowledge. Also, if learners lack relevant prior knowledge, a visual provided before the main lesson content can help to build an effective base knowledge structure. This skeleton structure provides a frame on which the learner can attach additional lesson details. Finally, a graphic that activates inappropriate prior knowledge will depress learning. For example, in Figure 4.2 we see an image and discussion of how airplanes are affected by lightning strikes. For a lesson on how lightning works, this interesting visual could activate inappropriate prior knowledge and depress learning.

Managing Mental Load

Since working memory is the site of active processing, good instructional materials must preserve its limited capacity for learning. This is especially important for novice learners who can only process small chunks of information as well as for anyone learning highly complex content. We have all had the experience of overload in courses jam-packed with lots of new and complex content presented rapidly in a lecture.

Visuals are one instructional method you can use to manage mental load. The type of graphic selected, how it is designed, and how it interfaces with other components of the instructional environment such as text all influence mental load. For example, a number of experiments show that a simpler visual such as a line drawing can often lead to better learning than a more complex 3D version.

Building Mental Models

The goal of instruction is to build mental models that improve job performance. Mental models are memory structures also called *schemas* that are stored in LTM. Mental models contain the knowledge and skills that help you make discriminations, interpret your environment, draw inferences, and solve problems. As we saw with the chess masters, experts have more mental models and their mental models are both more complex and better organized than the mental models of novices. Chess masters, for example, are estimated to have 50,000 play patterns stored in LTM. Learners build new mental models by integrating new lesson content with existing schemas activated from LTM. The integration of new content with existing mental models is called *encoding*. An effective visual is one that supports encoding of content to yield new and expanded mental models stored in LTM.

Transferring New Skills

It's not enough, however, to encode new mental models in LTM. Unless new skills can be brought back into WM when needed on the job, new mental models do little to improve work performance. Therefore, a process known as *transfer of learning* is critical. Without transfer, all the stored knowledge in the world does little good. Unfortunately, transfer failure is a common outcome of training. Learners may receive an A on a test in class but are unable to apply what they learned back on the job.

Transfer of learning relies on a psychological process called *retrieval*. During retrieval, new mental models built during training are brought back into WM to support completion of work tasks. In Chapter 9 we will see how to use visuals that promote retrieval.

Optimizing Motivation

These core cognitive processes of learning all depend on the learners' motivation. Motivation refers to any factor that encourages learners to initiate and to invest the effort needed to achieve a learning goal. One major source of motivation is interest, and developers of instructional materials often attempt to spice up technical lessons by adding dramatic but unessential vignettes to lessons. For example, an online course may use a popular movie theme in an attempt to make dry material more interesting. In Chapter 10 we will evaluate the effectiveness of these attempts at edutainment.

HOW GRAPHICS PROMOTE LEARNING

Recall that we started the chapter with summaries of some research studies in which some graphics promoted learning and different graphics depressed learning. To be effective, a visual must support any or several of the processes described in the previous section. Visuals that depress learning do so by disrupting one or more of those processes. In the following paragraphs we summarize six general principles for the use of visuals that promote learning and avoidance of graphics that disrupt cognitive processes.

1. Visuals and Text That Are Aligned with the Goals of the Instruction Improve Learning

Dual encoding, as it sounds, means two encodings of information into LTM—one that is based on words and a second one that is visual. Paivio (1990) proposed dual encoding to explain the learning benefits of adding visuals to text. According to dual encoding theory: "There are two distinct and independent but interconnected cognitive systems for processing and storing information: an imagery or nonverbal system for nonverbal information and a verbal system for linguistic information" (Vekiri, 2002, p. 266).

For example, in the lesson on lightning formation, the version that included a relevant visual representation as shown in Figure 4.1 together with a textual explanation of how lightning forms leads to two memory codes—a verbal code and a visual code. The visual is congruent with the text and both match the instructional goal. Therefore, the text and visual combine to increase the encoding opportunities and improve the probability of achieving the instructional goal.

2. Visuals That Are Misaligned with the Goals of the Instruction Depress Learning

Harp and Mayer (1997) found that visuals such as an airplane struck by lightning included in the lightning lesson to add interest depressed learning. The negative effect on learning could be caused by distraction and consequent disruption in building of a coherent mental model. Although visuals like these are added with the good intention of improving motivation, their negative effect on learning is counterproductive. Learners are better served by materials that use graphics that make the main lesson ideas more understandable than materials that add extraneous visuals for purposes of emotional interest.

3. Visuals Are More Efficient to Communicate Spatial Content

We mentioned previously that WM capacity is highly limited and the more those limited resources can be devoted to learning, the better. Often a visual can present information in a more concise way than can text. For example, if you compare the

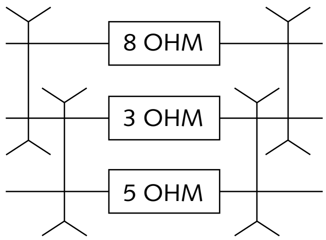
Figure 4.6. Task Directions Presented by Text and by a Graphic.

Text Format:

Using the resistors supplied, make the following connections:

- Connect one end of an 8 ohm resistor to one end of a 3 ohm resistor, and connect the other end of the 8 ohm resistor to the other end of the 3 ohm resistor
- Connect one end of the 3 ohm resistor to one end of a 5 ohm resistor, and connect the other end of the 3 ohm resistor to the other end of the 5 ohm resistor.

Diagrammatic Format:



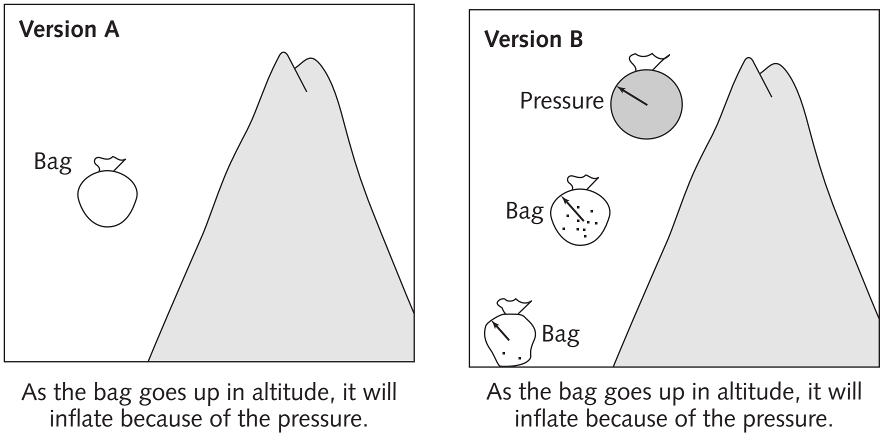
Adapted from Marcus, Cooper, and Sweller, 1996.

visual shown in Figure 4.6 with its textual equivalent, the visual communicates the same information in a more concise way. Marcus, Cooper, and Sweller (1996) compared the time needed to connect several resistors using text instructions to the time needed when using the visual. The visual representation resulted in faster performance.

4. Visuals That Depict Relationships Can Support Deeper Learning

Gyselinck and Tardieu (1999) compared two types of visuals in a science lesson on how gas pressures change at different altitudes. Representational illustrations showed the elements described in the text. For example, a mountain and a bag shown in Figure 4.7A illustrated the following text: "As the bag goes up in altitude, it will inflate because of the pressure" (p. 204). In a second version, the same text

Figure 4.7. A Representational (A) and an Interpretive Graphic (B) to Illustrate Gas Pressure.



From Gyselinck and Tardieu, 1999.

was illustrated by interpretive illustrations that included the mountain, the bag, and arrows depicting the internal and external gas pressures as shown in Figure 4.7B. This interpretive graphic illustrated both the elements described in the text and the relationship among those elements.

The research team found that recall memory was improved by both types of visuals. This may reflect the dual encoding process described above. However, the visual shown in Figure 4.7B that depicted the relationships described in the text resulted in better problem solving than the visuals that only represented elements of the text. Deeper learning will be stimulated by organizational, relational, transformational, and interpretive visuals, all of which depict relationships among lesson content. Collectively we refer to these four categories of visuals as *explanatory visuals* because they communicate relationships among content that promote building of mental models.

5. Simpler Visuals Are Often Better for Learning

We will review experiments in Chapter 7 showing that when your goal is to build understanding, a graphic with a less complex surface feature is often more effective.

For example, a line drawing can be more effective than a more realistic 3D image or photograph. Alternatively, a series of still visuals can be more effective than animations. An exception to this guideline is learning of motion skills that benefit from animated demonstrations processed by the mirror neuron system.

6. Visuals Ignored Don't Teach

None of these learning benefits would be realized if the visuals were ignored. Note in Figure 4.3 the label of *metacognition* in the top part of the visual. Metacognitive skills are the basis for your mental operating system. They manage and control all the learning processes we summarized in this chapter. Some people have better metacognitive skills than others and therefore take full advantage of graphics placed in training materials. Research has shown that learners who take additional time to carefully study visuals learn more from the lesson than those who do not (Gyselinck & Tardieu, 1999; Schnotz, Picard, & Hron, 1993). You can increase the opportunities to learn from your graphics by encouraging active engagement with them. We will describe specific ways to do so in Section Three.

THE BOTTOM LINE

Select and design visuals on the basis of their functionality as well as their surface features to maximize their potential. Based on our communication taxonomy shown in Table 1.3, graphics that depict elements of the text are representational visuals and will improve recall of content by way of dual encoding. The explanatory visuals that show relationships among the lesson concepts will improve problem solving by way of building mental models. Both types of visuals reduce load on working memory and thus improve mental efficiency. However, none of these psychological benefits will be realized unless the learner processes the visual.

COMING NEXT

Now that we have overviewed the major psychological events needed to support learning, in the following chapters we describe in greater detail how you can use graphics to promote each event. In the next chapter we begin with evidence and guidelines for ways you can use visuals and visual elements to focus learner attention.

For More Information

Clark, R.C. (2008) *Building expertise: Cognitive methods for learning and performance* (3rd ed.). San Francisco: Pfeiffer.

Mayer, R.E. (2011). *Applying the science of learning*. Boston: Pearson.

Mayer, R.E. (2009). *Multimedia learning* (2nd ed.). New York: Cambridge University Press. (See Chapters 4 and 12.)

Van Gog, T., Paas, F., Marcus, N., Ayres, P., & Sweller, J. (2009). The mirror neuron system and observational learning: Implications for the effectiveness of dynamic visualizations. *Educational Psychology Review*, *21*, 21–30.