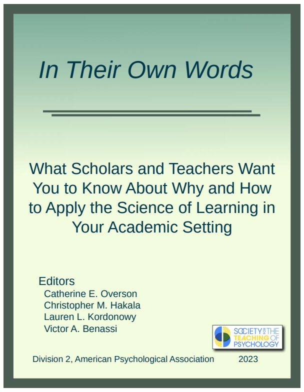


Research-Based Principles for Designing Multimedia Instruction

Richard E. Mayer
University of California, Santa Barbara

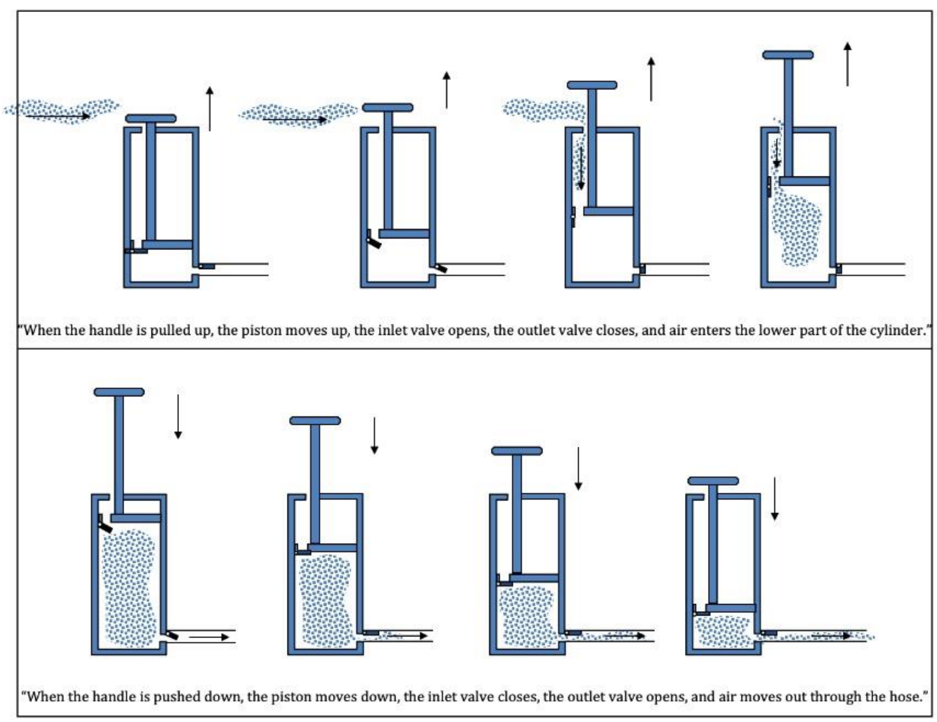
Overview of Multimedia Instruction

People learn more deeply from words and graphics than from words alone. This assertion can be called the *multimedia principle*, and it forms the basis for using *multimedia instruction*—that is, instruction containing words (such as spoken text or printed text) and graphics (such as illustrations, charts, photos, animation, or video) that is intended to foster learning (Mayer, 2021, in press-a).

For example, Figure 1 shows frames from a narrated animation on how a tire pump works. In this case the words are spoken, and the graphics are presented as an animation. Other examples include textbook lessons presented on paper, slideshow presentations presented face-to-face, instructional video or narrated animation or interactive tutorials presented via computer, educational games and simulations presented on hand-held devices, and immersive virtual reality or augmented reality learning experiences presented via head mounted displays. Regardless of presentation medium, what makes all these examples of multimedia instruction is that they use words and graphics to promote learning.

Figure 1

Frames from a Narrated Animation on How a Tire Pump Works



What is the evidence for the multimedia principle? In a series of 13 experimental comparisons my colleagues and I have found that students perform much better on a transfer test when they learn from words and graphics than from words alone (e.g., narration and animation versus narration alone, or text and illustrations versus text alone), yielding a median effect size of $d = 1.35$ (Mayer, 2021). For example, students are better able to answer troubleshooting questions about tire pumps after viewing the narrated animation shown in Figure 1 than after solely hearing the narration (Mayer & Anderson, 1991). In short, research shows that multimedia instruction has the potential to greatly improve student understanding of how things work, including tire pumps, brakes, generators, and lightning (Mayer, 2021, in press-a).

Although instruction has traditionally emphasized verbal modes of presentation (such as lectures and printed books), recent advances in graphics technology now allow more widespread incorporation of visual modes of presentation including illustrations, charts, photos, animation, and video in presentations and in interactive venues such as intelligent tutoring systems, games, simulations, and immersive virtual reality. However, not all graphics are equally effective so careful research is needed to pinpoint principles of multimedia instructional design. The goal of this chapter is to provide a brief overview of research-based principles for how to design effective instruction that uses words and graphics, based on research carried out by my colleagues and me and described more fully in Mayer (2021). A broader review of multimedia design principles is available in Mayer and Fiorella (in press-a).

An important starting point is to examine principles that are based on an understanding of how people learn from words and graphics. Figure 2 summarizes the cognitive theory of multimedia learning (Mayer, 2021, in press-b), which is based on three core assumptions derived from the science of learning (Mayer, 2011): *dual channel assumption*—people have separate channels for processing visual and verbal material (Paivio, 1986); *limited capacity assumption*—people can process only a limited amount of material in a channel at any one time (Baddeley, 1999; Sweller et al., 2011); and *active processing assumption*—meaningful learning occurs when learners select relevant material, organize it into a coherent structure, and integrate it with relevant prior knowledge (Fiorella & Mayer, 2015; Mayer, 2021; Wittrock, 1989).

Figure 2 represents memory stores as rectangles: *sensory memory,* which temporarily holds incoming images and sounds; *working memory*, which allows for mentally manipulating a small amount of the incoming visual and verbal material; and *long-term memory,* which is the learner's permanent storehouse of knowledge. Figure 2 represents cognitive processing as arrows: *selecting*, which transfers some of the incoming images and sounds to working memory for additional processing; *organizing,* which organizes the images into a pictorial model and the words into a verbal model in working memory; and *integrating,* which connects the pictorial and verbal models with each other and with relevant knowledge activated from long-term memory. A multimedia message enters the cognitive system through the learner's ears and eyes. The top row represents the verbal channel (into which spoken words and sounds enter) and the bottom row represents the visual channel (into which graphics and printed words enter), although in working memory printed words can be converted into sounds and images can be converted into spoken words. In working memory, the learner selects relevant words and images, organizes them into coherent verbal and pictorial representations, and integrates the representations with each other and with relevant knowledge activated from long-term memory.

Figure 2:

Cognitive Theory of Multimedia Learning

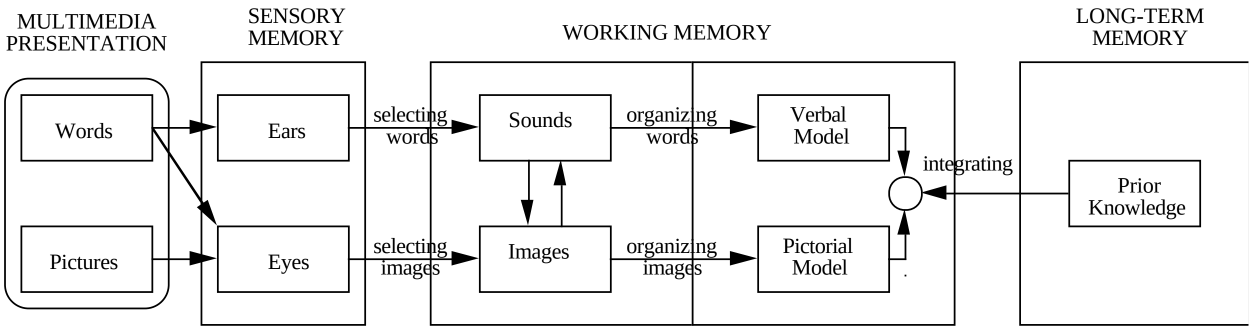


Table 1 summarizes three kinds of processing that can occur during multimedia instruction—*extraneous processing,* which drains limited cognitive processing capacity without contributing to learning and is caused by poor instructional design; *essential processing,* which involves selecting relevant information and organizing it in working memory as presented and is caused by the complexity of the material for the learner; and *generative processing*, which involves making sense of the material by reorganizing it into a coherent structure and integrating it with relevant prior knowledge and is caused by the learner's motivation to exert effort towards understanding. This analysis is similar to that proposed in cognitive load theory (Paas & Sweller, in press; Sweller, Ayres, & Kalyuga, 2011) and suggests the need for three kinds of instructional design goals—*reducing extraneous processing*, which applies when extraneous processing and required essential processing exceed the learner's cognitive capacity; *managing essential processing*, which applies when the required essential processing exceeds the learner's cognitive capacity; and *fostering generative processing*, which applies when the learner has processing capacity available but chooses not to exert the effort to use it for making sense of the material. These three types of goals form the basis for three kinds of instructional design principles for multimedia learning, which are presented in the next section.

Table 1

Three Kinds of Cognitive Processing During Learning

Cognitive processing	Description	Instructional goal
Extraneous	Not related to instructional goal, caused by poor instructional design	Reduce extraneous processing
Essential	Aimed at representing essential material, caused by complexity of material	Manage essential processing
Generative	Aimed at making sense of essential material, caused by learner's effort	Foster generative processing

Research on Design Principles for Multimedia Instruction

In this section I examine 13 research-based principles for how to design multimedia, including five principles aimed at reducing extraneous processing, three principles aimed at managing essential processing, and five principles aimed at fostering generative processing. For each principle, we conducted a meta-analysis and computed the median effect size based on Cohen's d (Cohen, 1988). Following Hattie (2009), we consider any effect size greater than $d = 0.40$ to be educationally important.

Reduce Extraneous Processing

Table 2 summarizes five principles aimed at reducing extraneous processing based on research conducted by my colleagues and me: the coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. The table specifies the number of experimental tests in which positive results were obtained and provides the median effect size based on a meta-analysis by Mayer (2021). A learner experiences *extraneous overload* when essential cognitive processing required to understand the essential material in a multimedia message and extraneous cognitive processing required to process extraneous material exceeds the learner's cognitive capacity. These five principles are intended to address the problem of extraneous overload by reducing extraneous cognitive processing.

Table 2

Five Research-Based Principles Based on Reducing Extraneous Processing

Principle	Description	Tests	Effect size
Coherence	Delete extraneous material	18 of 19	0.86
Signaling	Highlight essential material	26 of 28	0.70
Redundancy	Don't add onscreen captions to narrated graphics	8 of 12	0.10
Spatial contiguity	Place printed words near corresponding part of graphic	9 of 9	0.82
Temporal contiguity	Present spoken words at same time as corresponding graphics	8 of 8	1.31

Note. Based on Mayer (2021).

The Coherence Principle

The first technique for reducing extraneous processing is the coherence principle: People learn more deeply from a multimedia message when extraneous material is excluded rather than included. The rationale for the coherence principle is that people are better able to focus on the essential material if we eliminate extraneous material that could distract them. This principle was supported in 18 out of 19 experimental tests, yielding a median effect size of 0.86. For example, students who learned from a multimedia lesson on how a virus causes a cold performed better on a transfer test if the lesson did not contain seductive details—sentences that gave interesting but irrelevant facts about viruses (Mayer, Griffith, Jurkowitz, & Rothman, 2008). Similarly, students who learned from a narrated animation on lightning formation performed better on a transfer test if the lesson did not also contain short video clips depicting lightning strikes (Mayer, Heiser, & Lonn, 2001). Overall, similar effects have been noted in the broader literature (Fiorella & Mayer, in press-a; Rey, 2012; Sundarajan & Adesope, 2020). Concerning boundary conditions, reviews of the coherence principle suggest the effects may be strongest for learners with low rather than high working memory capacity, when the lesson is system-paced rather than learner-paced, and when the extraneous material is highly interesting rather than neutral (Mayer & Fiorella, in press-a; Rey, 2012; Sundarajan & Adesope, 2020).

The Signaling Principle

The second technique for reducing extraneous processing is the signaling principle: People learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material. The rationale for the signaling principle is that people will learn more efficiently if the lesson is designed to call their attention to the important material in the lesson and how it is organized. This principle was supported in 26 out of 28 experimental tests, yielding a median effect size of 0.70. Signaling of the verbal material includes using an outline, headings, highlighting (such as underlining) and pointer words (such as first, second, third), as well as placing stress on spoken words. Verbal signaling was effective in 15 out of 16 tests, yielding a median effect size of 0.69. For example, in a narrated animation on how an airplane achieves lift, students performed better on a transfer test if the narration included an initial outline, headings, and voice emphasis on key words (Mautone & Mayer, 2001). Signaling of visual material includes arrows, flashing, spotlighting, and pointing. Visual signaling was effective in 11 of 12 tests, yielding a median effect size of 0.71. Overall, signaling effects have been documented in the broader research literature (Richter, Scheiter, & Eitel, 2016; Schneider, Beege, Nebel, & Rey, 2018; van Gog, in press). Concerning boundary conditions, the signaling principle may apply most strongly when the learner might otherwise be overwhelmed with extraneous processing—such as, for low-knowledge learners rather than high-knowledge learners, for complex material rather than simple material, and when visual and verbal signals are used sparingly (Fiorella & Mayer, in press-a; Mayer, 2021).

Redundancy Principle

The third technique for reducing extraneous processing is the redundancy principle: People do not learn more deeply when on-screen text is added to narrated graphics. The rationale is that with redundant presentations people may waste precious processing capacity by trying to reconcile the two verbal streams of information (i.e., printed and spoken text) or may focus on the printed words rather than the relevant portions of the graphics. This principle was supported in 8 out of 12 experimental tests, yielding a median effect size of 0.10 favoring no onscreen text. For example, Moreno and Mayer (2002) reported that students performed better on a transfer test about lightning if they received a narrated animation about lightning formation rather than the same narrated animated with concurrent onscreen text inserted at the bottom of the screen. This work is consistent with the broader research literature on redundancy (Adesope & Nesbit, 2012; Kalyuga & Sweller, in press). Concerning boundary conditions, the redundancy effect can be diminished or even reversed when the lesson is slow-paced or under learner control, the on-screen text is short or in a reworded form, the words are in the learner's second language, or the material lacks graphics (Fiorella & Mayer, in press-a; Mayer, 2021).

The Spatial Contiguity Principle

The fourth technique for reducing extraneous processing is the spatial contiguity principle: People learn more deeply from a multimedia message when corresponding printed words and graphics are presented near rather than far from each other on the page or screen. The rationale is that spatial contiguity helps learners build connections between corresponding words and graphics. This principle was supported in 9 out of 9 experimental tests, yielding a median effect size of 0.82. For example, Moreno and Mayer (1999) found that students performed better on a transfer test after viewing an animation about lightning in which printed words were placed next to the part of the lightning system they described than when printed words were placed at the bottom of the screen as a caption. Similar results are reported in meta-analyses by Ginns (2006) and Schroder and Cenkci (2018) as well as in a review by Ayres and Weller (in press). Fiorella and Mayer (in press-a) report there is preliminary evidence that the spatial contiguity principle may be strongest for low prior knowledge learners, non-redundant text and pictures, complex lessons, and interactive formats.

The Temporal Contiguity Principle

The fifth technique for reducing extraneous processing is the temporal contiguity principle: People learn more deeply from a multimedia message when corresponding graphics and narration are presented simultaneously rather than successively. The rationale is that temporal contiguity helps learners build connections between corresponding words and graphics. This principle was supported in 8 out of 8 experimental tests, yielding a median effect size of 1.31. For example, students performed better on a transfer test when they received a narrated animation on how a tire pump works than when they heard the narration before or after the animation (Mayer and Anderson, 1991). Researchers have noted that the temporal contiguity principle may apply most strongly when lessons are long rather than short and when the lesson is system-paced rather than learner paced (Fiorella & Mayer, in press-a; Mayer, 2021).

Manage Essential Processing

Table 3 summarizes three principles aimed at managing essential processing: the segmenting, pre-training, and modality principles. The table specifies the number of experimental tests in which positive results were obtained and provides the median effect size based on a meta-analysis by Mayer (2021). These principles are intended to address the instructional problem of *essential overload,* which can occur when a fast-paced multimedia lesson contains material that is complicated for the learner. A learner experiences *essential overload* when the amount of essential cognitive processing required to understand the multimedia instructional message exceeds the learner's cognitive capacity.

Table 3

Three Research-Based Principles Based on Managing Essential Processing

Principle	Description	Tests	Effect size
Segmenting	Break lesson into learner-paced parts	7 of 7	0.67
Pre-training	Present characteristics of key concepts before lesson	10 of 10	0.78
Modality	Use spoken words rather than printed words	18 of 19	1.00

Note. Based on Mayer (2021).

The Segmenting Principle

The first technique for managing essential processing is the segmenting principle: People learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit. The rationale is that segmenting allows people to fully process one step in the process before having to move onto the next one. This principle was supported in 7 out of 7 experimental tests, yielding a median effect size of 0.67. For example, Mayer and Chandler (2001) found that students performed better on a transfer test if a narrated animation about lightning was broken into 16 10-second segments in which students could press a "continue" button to go on to the next segment.
Some potential boundary conditions are that segmenting may have stronger effects when the material is complex for the learner and when the lesson is otherwise fast-paced (Mayer & Fiorella, in press-b).

The Pre-training Principle

The second technique for managing essential processing is the pre-training principle: People learn more deeply from a multimedia message when they have learned the names and characteristics of the main concepts. The rationale is that pre-training allows students to focus on the causal connections in the multimedia explanation because they already know the names and characteristics of the key elements. This principle was supported in 10 out of 10 experimental tests, yielding a median effect size of 0.78. For example, students performed better on a transfer test based on a narrated animation on how brakes work if before the lesson they were introduced to the names and characteristics of key components mentioned in the lesson such as the piston and brake shoe (Mayer, Mathias, & Wetzell, 2002). However, some important boundary conditions are that the pre-training principle may not apply to high prior knowledge learners (perhaps because they are less likely to experience essential overload), when the material is simple for the learner, and when the lesson is slow-paced or under learner control (Mayer, 2021; Mayer & Fiorella, in press-b).

The Modality Principle

The third technique for managing essential processing is the modality principle: People learn more deeply from a multimedia message when the words are spoken rather than printed. The rationale is that the modality principle allows learners to off-load some of the processing in the visual channel (i.e., the printed captions) onto the verbal channel, thereby freeing more capacity in the visual channel for processing the graphics. This principle was supported in 18 out of 19 experimental tests, yielding a median effect size of 1.00. For example, Moreno and Mayer (1999) found that students performed better on a transfer test after receiving a narrated animation on lightning formation than after receiving the same animation with on-screen captions that contained the same words as the narration. Similar results are reported in reviews and meta-analyses covering the broader literature, subject to boundary conditions (Castro-Alonso & Sweller, in press; Ginns, 2005; Reinwein, 2012). As the most studied principle in the list, research shows that the modality principle should not be taken to mean that spoken words are better than printed words in all situations. Some important boundary conditions reported in some studies are that printed words may be effective when the verbal material contains technical terms, is in the learner's second language, or when the lesson is learner-paced; whereas spoken words may be effective when the lesson is fast-paced, is presented in segments that are too large to be held in the learner's working memory, and contains words that are familiar to the learner (Jiang & Sweller, in press; Mayer, 2021; Mayer & Fiorella, in press-b).

Foster Generative Processing

Table 4 summarizes five principles aimed at fostering generative processing: the personalization, voice, embodiment, image, and generative activity principles. The table specifies the number of experimental tests in which positive results were obtained and provides the median effect size based on a meta-analysis by Mayer (2021). Most of these principles use social cues to attempt to prime the learner's motivation to exert effort to make sense of the material. Social cues in a multimedia message such as conversational style, voice, and gesture are intended to prime a sense of social presence in learners that leads to deeper cognitive processing during learning and hence better test performance (Fiorella & Mayer, in press-b).

Table 4

Five Research-Based Principles Based on Fostering Generative Processing

Principle	Description	Tests	Effect size
Personalization	Put words in conversational style rather than formal style	13 of 15	1.00
Voice	Put words in human voice rather than machine voice	6 of 7	0.74
Embodiment	Have onscreen agent use human-like gestures and movements	16 of 17	0.58
Image	Do not necessarily put static image of agent on the screen	4 of 7	0.19
Generative activity	Prompt learners to engage in Generative learning activities	37 of 44	0.71

Note. Based on Mayer (2021).

The Personalization Principle

The first technique for fostering generative processing is the *personalization principle*: People learn more deeply when the words in a multimedia presentation are in conversational style rather than formal style. The rationale for this technique is that conversational style can prime a sense of social presence in the learner, which causes the learner to try harder to make sense of what the instructor is saying by engaging in appropriate cognitive processing during learning, leading to learning outcomes that are better able to support problem-solving transfer. This principle was supported in 13 out of 15 experimental tests, yielding a median effect size of d = 1.00 (Mayer, 2021). For example, Mayer, Fennell, Farmer and Campbell (2004) found that students performed better on a transfer test after receiving a narrated animation on how the human respiratory system works when conversational wording was used (e.g., “your lungs,” or “your nose”) rather than formal style (e.g., “the lungs” or “the nose”). Similar results are reported in a meta-analysis by Ginns, Martin, and Marsh (2013). Some important boundary conditions are that the personalization principle may not apply for experienced learners or long lessons (Fiorella & Mayer, in press-b; Mayer, 2021).

The Voice Principle

The second technique for fostering generative processing is the *voice principle*: People learn more deeply when the words in a multimedia message are spoken in an appealing human voice rather than in a machine voice. An appealing human voice is intended to prime a sense of social presence in learners. For example, Mayer, Sobko, and Mautone (2003) found that students performed better on a transfer test after receiving a narrated animation on lightning that used a human voice rather than a machine synthesized voice. This principle was supported in 6 out of 7 experimental comparisons, with a median effect size of 0.74. More recently, Craig and Schroder (2017, 2018) found that advances in modern text-to-speech engines can allow them to be more human-like. In a broader review of the instructional effects on onscreen agents, Schroeder and Adesope (2014, p. 247) concluded that "voice may be critical, whereas the image of the agent is not." Research shows that a possible boundary condition is that the voice principle may not apply when there are negative social cues such as low embodiment (Fiorella & Mayer, in press-b; Mayer, 2021).

The Embodiment Principle

The third technique for fostering generative processing is the *embodiment principle:* People learn more deeply when onscreen agents display human-like gesturing, movement, eye contact, and facial expression. Human-like action is intended to create a sense of social presence with the instructor. In 16 out of 17 experimental comparisons, people performed better on transfer tests when they learned from a high-embodied agent than from a low-embodied agent, yielding a median effect size of 0.58. For example, Mayer and DaPra (2012) found that students performed better on a transfer test after viewing an online slideshow that was narrated by an onscreen agent who used human-like gesture, facial expression, eye gaze, and movement than an onscreen agent who did not move, gesture, gaze, or show expression. As another example, Fiorella and Mayer (2016) reported that students performed better on a transfer test after watching a video showing an instructor drawing on a board as she lectured rather than gesturing towards already drawn graphics. As yet another example of embodiment, Fiorella, van Gog, Hoogerheide, and Mayer (2017) found that students learned better from a video demonstration filmed from a first-person perspective (i.e., with camera over the instructor's shoulder) rather than a third-person perspective (i.e., with the camera across from the instructor). A meta-analysis involving the broader literature determined that students learn better from multimedia lessons when onscreen agents use pointing gestures (Davis, 2018). A possible boundary condition is that the embodiment principle may not apply when there are negative social cues such as machine voice (Fiorella & Mayer, in press-b; Mayer, 2021).

The Image Principle

The fourth technique in Table 4 is the *image principle*: People do not necessarily learn more deeply from a multimedia presentation when the speaker's image is on the screen rather than not on the screen. Having a static image may cause distraction that detracts from any social benefits. For example, Mayer, Dow, and Mayer (2003) found that adding the image of an onscreen character did not improve learning much (d = 0.19) from a narrated animation on how electric motors work. This principle is based on 7 experimental tests in which 3 produced negative effects, yielding a median effect size of 0.19. In a review of research on onscreen agents, Schroeder and Adesope (2014) also concluded that a static image of the agent on the screen does not boost learning. Concerning boundary conditions, the image principle applies for low-embodiment onscreen agents, that is, onscreen agents that do not move (Fiorella & Mayer, in press-b; Mayer, 2021).

The Generative Activity Principle

Finally, another way to foster generative processing during learning is to prompt and guide students in carrying out generative activities during learning, consistent with generative learning theory (Fiorella & Mayer, 2015, in press-c; Wittrock, 1989). Generative learning theory holds that deep learning occurs when learners mentally construct new knowledge through the processes of reorganizing incoming information and integrating it with relevant prior knowledge. The *generative activity principle* states: People learn more deeply when they are prompted and guided in carrying out generative learning activities during learning. Our research has shown that students perform better on transfer tests when they are prompted to carry out generative learning activities during learning from a lesson, such as producing a verbal summary or a concept map, making or imagining an illustration corresponding to presented text, taking a practice test on the material, explaining the material to oneself or others, or physically moving objects to act out the lesson. In 37 out of 44 experimental comparisons, students who were prompted to engage in these generative learning activities achieved higher transfer test scores than those who were not, yielding a median effect size of 0.71. In reviews of the broader literature, Fiorella and Mayer (2015) found similar positive effects on learning outcomes when students are prompted and guided to engage in summarizing (*d* = 0.50 based on 30 tests), mapping (*d* = 0.62 based on 39 tests), drawing (*d* = 0.40 based on 28 tests), imagining (*d* = 0.65 based on 22 tests), self-testing (*d* = 0.57 based on 76 tests), self-explaining (*d* = 0.61 based on 54 tests), teaching (*d* = 0.77 based on 19 tests), and enacting (*d* = 0.51 based on 49 tests). Concerning boundary conditions, generative learning activities are most powerful when learners have appropriate training and guidance in how to use them, and when the activities are properly scaffolded so as to not be too cognitively demanding (Fiorella & Mayer, in press-c; Mayer, 2021).

Practical Application of Design Principles for Multimedia Instruction

The principles summarized in this chapter are based on research and grounded in cognitive theory, but more work is needed to better delineate the boundary conditions under which the principles apply and to extend the domain of study. In particular, most of the supporting research involves short-term laboratory studies, so it is useful to determine the degree to which the principles apply in more authentic learning situations such as in schools, online courses, or workplace training (Clark, in press; Clark & Mayer, 2016). For example, a promising step in this direction involves a finding by Issa et al. (2013) showing that redesigning a medical school classroom slideshow lecture on shock based on multimedia principles resulted in improvements on an immediate transfer test (*d* = 0.76) and a delayed transfer test (*d* = 1.17).

The principles presented in this chapter are intended to apply to a range of instructional scenarios ranging from textbooks to face-to-face slide show presentations to computer-based lessons to interactive games and simulations to online courses to learning in immersive virtual reality. Within a classroom, these principles apply to the design of classroom printed materials, computer-based exercises and simulations, and face-to-face instruction including slideshow presentations.

For example, suppose you wished to apply research-based multimedia design principles to improve a short, narrated slideshow on how a solar cell works for presentation in an environmental science class.

- First, in deference to the coherence principle, you might decide to prune interesting but irrelevant material that you had downloaded from the Internet, including photos of a solar cell installation in a desert in southern California and a short video clip you found in which Al Gore envisions the coming environmental disaster. In short, you work to weed out images and words that are not essential to explaining how a solar cell works, including eliminating entire slides or parts of slides.
- Based on the pre-training principle you begin with a slide that that depicts the key elements (such as the “positive side” and “negative side” of the solar cell) along with a verbal label next to each key element, perhaps connected with a line.
- In deference to the signaling principle, you place a heading at the top of each of the remaining 10 slides, which succinctly describes the step in the process being depicted. In addition, you use arrows to show the movement of electrons within the solar cell, corresponding to the description in the narration.
- In line with the segmenting principle, you break the illustration on each slide into segments that you progressively add in sync with your narration.
- In line with the modality principle, you mainly use narration to convey the verbal material.
- Corresponding to the redundancy principle, you present only short, printed phrases on the slides, rather than captions that duplicate what you are saying. In this case, the strictest

interpretation modality principle and the redundancy principle can be modified by including a minimal number of words on the screen—mainly, to help highlight the main points and to concretize technical or unfamiliar terms.

- In line with the spatial contiguity principle, you place the short text phrases describing the action next to the corresponding part of the graphic (such as putting "Electrons move across the barrier" next to an arrow from one side of the barrier to another) rather than at the bottom of the graphic.
- In line with the personalization principle, you use first- and second- person style (such as saying, "Let's see how a solar cell works." rather than "This lesson tells how a solar cell works.").
- Consistent with the embodiment principle, you stand next to the slide as you talk, pointing out what you are talking about and maintaining a smile and eye contact with the audience.
- Based on temporal contiguity, you are careful to choreograph your speech so that it corresponds to what you are pointing to in the graphic.
- In line with the voice principle, you practice to make sure you use a pleasant, flowing voice that exudes positive affect, confidence, and warmth.
- In line with the image principle, you remove a distracting logo from each slide which shows Al Gore's face looking down along with the slogan: "LIVE GREEN."
- To bolster the generative activity principle, you ask students to write a one-sentence summary of each slide in their own words.

All in all, this example demonstrates how to accomplish your goal of removing material that primes extraneous processing, helping learners understand a complex system by using techniques such as segmenting and pre-training, and fostering deeper processing by creating a feeling of social conversation and priming generative learning activities. I will consider this chapter to be a success to the extent that instructors and instructional designers are able to improve student learning by adapting the principles presented in this chapter and other evidence-based principles (see Clark & Mayer, 2016; Mayer & Fiorella, in press-a).

Author Note

Preparation of this chapter was supported by a grant from the Office of Naval Research.

This chapter is an updated version of Mayer (2014) and is based on Mayer (2021).

References

Adesope, O. O., & Nesbit, J. C. (2012). Verbal redundancy in multimedia learning environments: A meta-analysis. *Journal of Educational Psychology, 104*(1), 250-263. https://doi.org/10.1037/a0026147

Ayres, P., & Sweller, J. (in press). The split-attention principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Baddeley, A. D. (1999). *Human memory*. Allyn & Bacon.

Castro-Alonso, J. C., & Sweller, J. (in press). The modality principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Clark, R. C. (in press). Multimedia-learning in e-courses. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Clark, R. C., & Mayer, R. E. (2016). *e-Learning and the science of instruction* (4th ed). Wiley.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* Erlbaum.

Craig, S. D., & Schroeder, N. L. (2017). Reconsidering the voice effect when learning from a virtual human. *Computers & Education, 114,* 193-205. https://doi.org/10.1016/j.compedu.2017.07.003

Craig, S. D., & Schroeder, N. L. (2018). Text-to-speech software and learning: Investigating the relevancy of the voice effect. *Journal of Educational Computing Research, 57*(6)*,* 1534-1548. https://doi.org/10.1177/0735633118802877

Davis, R. O. (2018). The impact of pedagogical agent gesturing in multimedia learning environments: A meta-analysis. *Educational Psychology Review, 24,* 193-209. http://dx.doi.org/10.1016/j.edurev.2018.05.002

Fiorella, L., & Mayer, R. E. (2015). *Learning as a generative activity.* Cambridge University Press.

Fiorella, L., & Mayer, R. E. (2016). Effects of observing the instructor draw diagrams on learning from multimedia messages. *Journal of Educational Psychology, 108*(4), 528-546. https://doi.org/10.1037/edu0000065

Fiorella, L., & Mayer, R. E. (in press-a). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Fiorella, L., & Mayer, R. E. (in press-b). Principles based on social cues in multimedia learning: Personalization, voice, embodiment, and image principles. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Fiorella, L., & Mayer, R. E. (in press-c). The generative activity principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Fiorella, L., van Gog, T., Hoogerheide, V., & Mayer, R. E. (2017). It's all a matter of perspective: Viewing first-person video modeling examples promotes learning of an assembly task. *Journal of Educational Psychology, 109*(5), 653-665. https://doi.org/10.1037/edu0000161

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15*(4), 313-332. https://doi.org/10.1016/j.learninstruc.2005.07.001

Ginns, P. (2006). Integrating information: A meta-analysis of spatial contiguity and temporal contiguity effects. *Learning and Instruction, 16*(6)*,* 511-525. https://doi.org/10.1016/j.learninstruc.2006.10.001

Ginns, P., Martin, A.J., & Marsh, H.M. (2013). Designing instructional text in a conversational style: A meta-analysis. *Educational Psychology Review, 25,* 445-472. https://doi.org/10.1007/s10648-013-9228-0

Hattie, J. (2009). *Visible learning.* Routledge.

Issa, N., Mayer, R. E., Schuller, M., Wang, E., Shapiro, M. B., & DaRosa, D. A. (2013). Teaching for understanding in medical classrooms using multimedia design principles. *Medical Education, 47,* 388-396. https://doi.org/10.1111/medu.12127

Jiang, D., & Sweller, J. (in press). The transient information principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Kalyuga, S., & Sweller, J. (in press). The redundancy principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Mautone, P. D. & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2), 377-389. https://doi.org/10.1037/0022-0663.93.2.377

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

Mayer, R. E. (2014). Research-based principles for designing multimedia instruction. In V. A. Benassi, C. E. Overson, & C. M. Hakala (Eds.), *Applying the science of learning in education: Infusing psychological science into the curriculum*. (59-70). Society for the Teaching of Psychology, http://teachpsych.org/ebooks/asle2014/index.php

Mayer, R. E. (2021). *Multimedia learning* (3rd ed). Cambridge University Press.

Mayer, R. E. (in press-a). Multimedia principle. In In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Mayer, R. E. (in press-b). Cognitive theory of multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Mayer, R. E., & Anderson, R. B. (1991). Animations need narrations: An experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83*(4), 484-490. https://doi.org/10.1037/0022-0663.83.4.484

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 93*(2), 390-397. https://doi.org/10.1037/0022-0663.93.2.390

Mayer, R. E., & DaPra, C. S. (2012). An embodiment effect in computer-based learning with animated pedagogical agent. *Journal of Experimental Psychology: Applied, 18*(3), 239-252. https://doi.org/10.1037/a0028616

Mayer, R. E., Dow, G., & Mayer, R. E. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*(4), 806-813. https://doi.org/10.1037/0022-0663.95.4.806

Mayer, R. E., Fennell, S., Farmer, L., & Campbell, J. (2004). A personalization effect in multimedia learning: Students learn better when words are in conversational style rather than formal style. *Journal of Educational Psychology, 96*(2), 389-395. https://doi.org/10.1037/0022-0663.96.2.389

Mayer, R. E. & L. Fiorella (Eds.). (in press-a). *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Mayer, R. E., & Fiorella, L. (in press-b). Principles for managing essential processing in multimedia learning: Segmenting, pre-training, and modality principles. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Mayer, R. E., Griffith, E., Jurkowitz, I. T. N., & Rothman, D. (2008). Increased interestingness of extraneous details in multimedia science presentation leads to decreased learning. *Journal of Experimental Psychology: Applied, 14*(4), 329-339. https://doi.org/10.1037/a0013835

Mayer, R. E., Heiser, H., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187-198. https://doi.org/10.1037/0022-0663.93.1.187

Mayer, R. E., Mathias, A., & Wetzell, K. (2002). Fostering understanding of multimedia messages through pre-training: Evidence for a two-stage theory of mental model construction. *Journal of Experimental Psychology: Applied, 8*(3), 147-154. https://doi.org/10.1037/1076-898X.8.3.147

Mayer, R. E., Sobko, K., & Mautone, P. D. (2003). Social cues in multimedia learning: Role of speaker's voice. *Journal of Educational Psychology, 95*(2), 419-425. https://doi.org/10.1037/0022-0663.95.2.419

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91*(2), 358-368. https://doi.org/10.1037/0022-0663.91.2.358

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology, 94*(3), 598-610. https://doi.org/10.1037/0022-0663.94.3.598

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford University Press.

Paas, F., & Sweller, J. (in press). Implications of cognitive load theory for multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Reinwein, J. (2012). Does the modality effect exist? And is so, which modality effect? *Journal of Psycholinguistic Research, 41,* 1-32. https://doi.org/10.1007/s10936-011-9180-4

Rey, G. D. (2012). A review and a meta-analysis of the seductive detail effect. *Educational Research Review, 7*(3), 216-237. https://doi.org/10.1016/j.edurev.2012.05.003

Richter, J., Scheiter, K., & Eitel, A. (2016). Signaling text-picture relations in multimedia learning: A comprehensive meta-analysis. *Educational Psychology Review, 17*, 19-36. https://doi.org/10.1016/j.edurev.2015.12.003

Schneider, S., Beege, M., Nebel, S., & Rey, G. D. (2018). A meta-analysis of how signalling affects learning with media. *Educational Psychology Review, 23,* 1-14. https://doi.org/10.1016/j.edurev.2017.11.001

Schroeder, N. L., & Adesope, O. O. (2014) A systematic review of pedagogical agents' persona, motivation, and cognitive load implications for learners. *Journal of Research on Technology in Education, 46*(3), 229-251. https://doi.org/10.1080/15391523.2014.888265

Schroeder, N. L., & Cenkci, A. T. (2018). Spatial contiguity and spatial split-attention effects in multimedia learning environments: A meta-analysis. *Educational Psychology Review, 30,* 679-701. https://doi.org/10.1007/s10648-018-9435-9

Sundararajan, N., & Adesope, O. (2020). Keep it coherent: A meta-analysis of the seductive details effect. *Educational Psychology Review, 32,* 707-734. https://doi.org/10.1007/s10648-020-09522-4

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory.* Springer.

Van Gog, T. (in press). The signaling (or cueing) principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed). Cambridge University Press.

Wittrock, M. C. (1989). Generative processes of comprehension. *Educational Psychologist, 24*(4), 345-376. https://doi.org/10.1207/s15326985ep2404_2