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Applying the Science of Learning: Evidence-Based Principles for the Design of Multimedia Instruction

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During the last 100 years, a major accomplishment of psychology has been the development of a science of learning aimed at understanding how people learn. In attempting to apply the science of learning, a central challenge of psychology and education is the development of a science of instruction aimed at understanding how to present material in ways that help people learn. The author provides an overview of how the design of multimedia instruction can be informed by the science of learning and the science of instruction, which yields 10 principles of multimedia instructional design that are grounded in theory and based on evidence. Overall, the relationship between the science of learning and the science of instruction is reciprocal.

Keywords: science of learning, science of instruction, multimedia learning, instructional design, evidence-based practice

Suppose you want to design (or select) (a) a computer-based training program to teach employees how to use a new database program, (b) a biology textbook for high school students, (c) an instructional video game aimed at promoting healthy eating, or even (d) a PowerPoint presentation on a topic in educational psychology. Each of these is an example of what I call a multimedia instructional message—a lesson containing words (e.g., printed words or spoken words) and pictures (e,g., illustrations, photos, animation, or video) that is intended to foster learning. How would you decide the best way to present your multimedia instruction? To help answer this question, you need some way of judging whether a proposed instructional method is consistent with research-based theories of how people learn (i.e., the science of learning) and evidence-based principles of how to design instruction (i.e., the science of instruction).

Let's consider three approaches to the relation between theory and practice (Mayer, 1992). In the one-way street approach, psychologists develop a theory of how people learn that is based on research, and educators apply the theory in their lessons. The problem with the one-way street approach is that a clear specification of how people learn does not automatically yield a clear specification of effective instructional methods and materials. In the dead end street approach, psychologists busy themselves in building a theory of learning that is not closely related to authentic educational challenges—such as studying how laboratory animals run mazes or how adults memorize word lists—while educators seek research that determines the best method of instruction without regard to how or why it works. Finally, in the two-way street approach, there is a reciprocal relation between learning theory and educational practice in which the science of learning must be expanded to be able to explain how learning works in authentic learning situations, and the science of instruction must be expanded to consider the conditions for each instructional principle based on an understanding of how the human mind works.

Figure 1 summarizes the relation between basic research—which has been attributed to the science of learning (SOL)—and applied research—which has been attributed to the science of instruction (SOI). A defining feature of the science of instruction is a focus on authentic learning situations rather than contrived learning situations, so Figure 1 shows "SOI" in the two quadrants on the right. A defining feature of the science of learning is a focus on testing learning theory, so "SOL" is shown in the two quadrants at the bottom of the figure. The four quadrants in Figure 1 are inspired by the work of Stokes (1997). The top left quadrant—conducting nontheoretical studies on contrived learning situations—is consistent with neither the SOL nor the SOI and is unlikely to yield information that is helpful for theory or practice. The top right quadrant—conducting nontheoretical studies on authentic tasks—is consistent with the SOI but not with the SOL. It represents pure applied research that is consistent with the dead end street approach. The result is likely to be a set of empirically based design principles that are of limited applicability because they are not tied to an understanding of how or why they work. The bottom left quadrant—conducting the-

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Richard E. Mayer received the Award for Distinguished Contributions of Applications of Psychology to Education and Training. Award winners are invited to deliver an award address at the APA's annual convention. A version of this award address was delivered at the 116th annual meeting, held August 14–17, 2008, in Boston, Massachusetts. Articles based on award addresses are reviewed, but they differ from unsolicited articles in that they are expressions of the winners' reflections on their work and their views of the field.

Figure 1
The Overlap Between Theoretical and Practical Research

	No SOI: Addresses a contrived learning situation	SOI: Addresses an authentic learning situation
No SOL: Does not test learning theory		SOI only
SOL: Tests learning theory	SOL only	SOL and SOI

Note. SOI = science of instruction; SOL = science of learning.

oretical studies on contrived tasks—is consistent with the SOL but not with the SOI. This quadrant represents pure basic research that is consistent with the one-way street approach. The result is likely to be a research-based theory of limited applicability, because it can explain learning in contrived lab settings but not necessarily in real-world settings. Finally, the bottom right quadrant—conducting theoretical studies on authentic tasks—is consistent with both the SOL and the SOI. This type of research reflects a two-way street approach, which Stokes (1997, p. 73) called "use-inspired basic research" and which I call *basic research on applied problems.* In this article, I explore the benefits of conducting basic research on applied problems by merging the goals of the science of learning and the science of instruction.

My goal in this article is to show how it is possible to conduct educational research that simultaneously applies the science of learning to an authentic practical problem (i.e., moving from the lower left quadrant of Figure 1 to the lower right quadrant) and grounds the science of instruction in research-based theory (moving from the upper right quadrant of Figure 1 to the lower right quadrant). In the following sections, I provide an overview of how the design of multimedia instruction can be informed by the science of learning and by the science of instruction, and I end the article with a closer look at principles of multimedia instructional design that are grounded in theory and based on evidence.

The Science of Learning

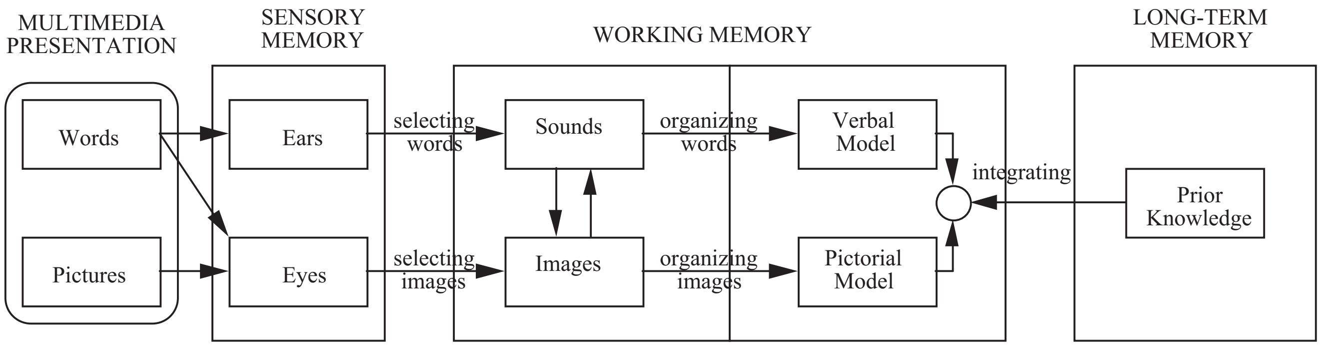
What is learning? During the past 100 years, a major accomplishment of psychology has been the development of a science of learning aimed at understanding how people learn. In particular, learning is a change in the learner's knowledge that is attributable to experience. Learning depends on the learner's cognitive processing during learning and includes (a) selecting—attending to the relevant incoming material; (b) organizing—organizing the incoming material into a coherent mental representation; and (c) integrating—relating the incoming material with existing knowledge from long-term memory.

What is multimedia learning? Multimedia learning is learning from words and pictures. The words can be printed text or spoken text. The pictures can be in static form, such as illustrations, photos, diagrams, charts, or maps, or in dynamic form, such as animation or video. Examples of multimedia learning include watching and listening to a narrated animation, reading a science textbook, playing an educational video game, or attending a PowerPoint presentation.

How does multimedia learning work? The most relevant elements in a science of learning are (a) dual channels—the idea that humans possess separate channels for processing visual and verbal material; (b) limited capacity—the idea that each channel can process only a small amount of material at any one time; and (c) active processing—the idea that deep learning depends on the learner's cognitive processing during learning (e.g., selecting, organizing, and integrating).

Figure 2 summarizes the cognitive theory of multimedia learning, which is intended as a framework for explaining how multimedia learning works (Mayer, 2001). The boxes represent memory stores, and the arrows represent cognitive processes. The cognitive theory of multimedia learning is consistent with the three learning principles summarized above. On the left in Figure 2, the learner begins with the words and pictures in a multimedia instructional message—which can be a textbook lesson, an online presentation, an interactive game, or even a PowerPoint presentation. In the second column—Sensory Memory—spoken words impinge on the ears and are represented briefly in auditory sensory memory, whereas pictures and printed words impinge on the eyes and are represented briefly in visual sensory memory. In the third column—the leftmost part of Working Memory—the learner selects some sounds for further processing in the verbal channel and some images for further processing in the pictorial channel (and may convert printed text into spoken text, which is also processed in the verbal channel). In the next column—the rightmost part of Working Memory—the learner organizes

Figure 2
Cognitive Theory of Multimedia Learning



Note. Reprinted from "Cognitive Constraints on Multimedia Learning: When Presenting More Material Results in Less Understanding," R. E. Mayer, H. Heiser, & S. Lonn, 2001, *Journal of Educational Psychology, 93,* Figure 2, p. 190. Copyright 2001 by the American Psychological Association.

some of the sounds into a verbal model and organizes some of the images into a pictorial model. In the final column—Long-Term Memory—the learner can activate prior knowledge to be integrated with the verbal and pictorial models in working memory and can store the resulting knowledge in long-term memory.

Selecting words and *selecting images* involve attending to relevant incoming material entering the ears and eyes, respectively. *Organizing words* and *organizing images* involve building coherent cognitive structures for the verbal material and the pictorial material, respectively. *Integrating* refers to building appropriate connections between the verbal and pictorial representations in working memory as well as relevant prior knowledge activated from long-term memory.

The Science of Instruction

What is instruction? In attempting to apply the science of learning, a central challenge of psychology and education is the development of a science of instruction aimed at understanding how to help people learn. Instruction refers to the instructor's manipulations of the environment that are intended to foster changes in knowledge in the learner. The science of instruction is concerned with how to present material in ways that prime appropriate cognitive processing during learning.

What is a learning objective? If learning is a change in the learner's knowledge that is due to experience, then a first step in instructional design is to clearly describe the intended change in knowledge (Anderson et al., 2001). An instructional objective is a clear description of the intended learning outcome.

What is a learning outcome? A learning outcome refers to the change in the learner's knowledge as a result of instruction. "Knowing what students know" (Pellegrino, Chudowsky, & Glaser, 2001, p. 1) is a basic challenge of the science of educational measurement. Two classic ways to measure learning outcomes are retention tests, which focus on remembering, and transfer tests, which focus on understanding. In a retention test, the learner is asked to recall or recognize parts of the presented material, as reflected in the item "Please write down everything you can remember from the lesson you just received." In a transfer test, the learner is asked to evaluate or use what was presented in a new situation, such as in the item "Please tell how you would improve the reliability of the device you just read about."

How does instruction work? The central issue in the science of instruction concerns how to help people learn. Instruction works by priming appropriate cognitive processing in the learner during learning, that is, by guiding the learner's selecting of relevant material, organizing of the material into a coherent cognitive representation, and integrating of the representation with other relevant knowledge. The central challenge of instructional design is how to encourage learners to engage in appropriate cognitive processing during learning while not overloading the processing capacity of the verbal or pictorial channel.

Key elements in the science of instruction are (a) reducing extraneous processing—cognitive processing that does not support the instructional goal and is attributable to confusing instructional design; (b) managing essential processing—cognitive processing needed to mentally represent the incoming material and that is attributable to the complexity of the material; and (c) fostering generative processing—cognitive processing aimed at making sense of the incoming material, including organizing it and integrating it with prior knowledge (Mayer, 2005; Sweller, 1999).

Table 1
Five Evidence-Based and Theoretically Grounded Principles for Reducing Extraneous Processing

Principle	Definition	Effect Size (d)	Number of Tests
Coherence	Reduce extraneous material.	0.97	13 of 14
Signaling	Highlight essential material.	0.52	6 of 6
Redundancy	Do not add on-screen text to narrated animation.	0.72	5 of 5
Spatial contiguity	Place printed words next to corresponding graphics.	1.12	5 of 5
Temporal contiguity	Present corresponding narration and animation at the same time.	1.31	8 of 8

What is an evidence-based approach? A guiding requirement of the science of instruction is that instructional practice be based on empirical evidence. Although there are many acceptable research methods—including experimental and observational methods—and many acceptable measures—including quantitative and qualitative measures (Shavelson & Towne, 2002), when the goal is to make a causal claim about instructional effectiveness, an extremely useful approach is to use experimental methods with quantitative measures (Phye, Robinson, & Levin, 2005). One methodology for generating evidence-based principles is to conduct a controlled experiment in which a control group receives a lesson that lacks the to-be-tested feature and an experimental group receives an otherwise identical lesson that contains the to-be-tested feature (Phye et al., 2005). The learning outcome is measured using a transfer test that yields means and standard deviations for the control and experimental groups. An effect size based on Cohen's (1988) d is then computed, in which the mean of the control group is subtracted from the mean of the experimental group and divided by the pooled standard deviation. According to Cohen, an effect size greater than 0.8 is considered large, an effect size greater than 0.5 is considered medium, and an effect size greater than 0.2 is considered small. The approach used in my lab is to conduct multiple comparisons involving the same instructional feature and to determine the median effect size.

Theoretically Grounded and Evidence-Based Principles for the Design of Multimedia Instruction

As an example of applying the science of learning, consider how to design multimedia instructional messages—lessons that include words (such as spoken or printed text) and pictures (such as illustrations, graphs, maps, photos, animation, or video). Over the past 20 years, my colleagues and I at the University of California, Santa Barbara have conducted dozens of experimental comparisons, which have yielded 10 evidence-based principles for the design of multimedia learning environments. The principles are theoretically grounded in the sense that they are consistent with the cognitive theory of multimedia learning, including its assumptions concerning dual channels, limited capacity, and active learning. The principles are evidence-based in the sense that they are based on multiple experimental comparisons that generally yielded large effect sizes. In this section, I summarize five principles for reducing extraneous processing, three principles for managing essential processing, and two principles for fostering generative processing.

Five Principles for Reducing Extraneous Processing

Perhaps the most serious problem with most ineffective multimedia lessons is that they cause the learner to engage in extraneous processing—cognitive processing that wastes precious cognitive capacity but does not help the learner build an appropriate cognitive representation. Table 1 lists five instructional methods intended to reduce extraneous processing, with each keyed to overcoming a specific kind of design problem.

First, consider a narrated animation that explains how lightning storms develop. In order to spice up the lesson, one could insert interesting facts (such as "Each year 150 people are killed by lightning strikes"), interesting video clips (such as an 8-s clip showing a spectacular lightning storm), or soothing background music (such as an instrumental loop). In 13 out of 14 experiments conducted in our lab, involving computer-based lessons on lightning, ocean waves, and brakes and paper-based lessons on lightning and ocean waves, students performed better on a problem-solving transfer test after receiving a concise lesson rather than an expanded lesson (Harp & Mayer, 1997, Experiment 1; Harp & Mayer, 1998, Experiments 1, 2, 3, and 4; Mayer, Bove, Bryman, Mars, & Tapangco, 1996, Experiments 1 and 2; Mayer, Heiser, & Lonn, 2001, Experiment 3; Mayer & Jackson, 2005, Experiments 1a, 1b, and 2; Moreno & Mayer, 2000a, Experiments 1 and 2). The median effect size (d) was 0.97, which is considered a large effect. According to the cognitive theory of multimedia learning, inserting extraneous material may cause learners to engage in extraneous processing—by using their processing capacity to attend to and process material that is not essential to building a mental model of the to-be-learned system. Learners given an expanded lesson may have less cognitive capacity for processing the essential material and therefore may be less likely to build a learning outcome that can be used to generate useful answers on a transfer test. As summarized in the top line of Table 1, the *coherence principle* is that people learn better when extraneous material is excluded rather than included in a multimedia lesson.

Second, consider a narrated animation that explains how airplanes achieve lift. The lesson contains some interesting but extraneous details, but it is not possible to delete the extraneous material. What can be done to minimize extraneous processing? One technique—*signaling*—involves highlighting the essential material in the lesson, such as by adding an overview sentence at the start of the narration that restates the three main ideas, adding headings for each section in the narration that correspond to the three main ideas in the overview, and emphasizing main ideas in the narration by stressing them vocally. In 6 out of 6 experiments, involving both computer-based lessons on airplanes and paper-based lessons on lightning and biology, learners who received signaled lessons performed better on transfer tests than students who received nonsignaled lessons (Harp & Mayer, 1998, Experiment 3a; Mautone & Mayer, 2001, Experiments 3a and 3b; Stull & Mayer, 2007, Experiments 1, 2, and 3). The median effect size was 0.52, which is considered a medium effect. As shown in the second line of Table 1, the *signaling principle* is that people learn better from a multimedia lesson when essential words are highlighted. According to the cognitive theory of multimedia learning, signaling can help guide the learner's attention toward the essential material, thereby minimizing the learner's processing of extraneous material.

Third, consider a narrated lesson on lightning in which concurrent on-screen text is added to the bottom of the screen. As the narrator says a sentence, the sentence appears at the bottom of the screen. One might think that adding redundant on-screen text to a narrated animation would be helpful because people who prefer to read can read and people who prefer to listen can listen. However, according to the cognitive theory of multimedia learning, adding on-screen text can create extraneous processing because the learner tries to reconcile the two incoming verbal streams and must scan between the text at the bottom of the screen and the relevant portion of the animation. As predicted, in 5 out of 5 experiments, involving computer-based lessons on lightning and environmental science, people who received animation and narration performed better on a transfer test than people who received animation, narration, and on-screen text (Mayer et al., 2001, Experiments 1 and 2; Moreno & Mayer, 2002a, Experiment 2; Moreno & Mayer, 2002b, Experiments 2a and 2b). The median effect size was 0.72, which is a medium effect. As shown in the third line of Table 1, the *redundancy principle* is that people learn better from animation and narration than from animation, narration, and on-screen text. The on-screen text creates extraneous processing that diminishes cognitive capacity available for deep learning.

So far, I have examined situations in which having too much extraneous material in a lesson caused extraneous processing by the learner. Now, let's consider a situation in which extraneous processing is caused by poor layout of the page or screen rather than by too much extraneous material. For example, in a paper-based lesson on how car brakes work, suppose the text is placed in a caption below a two-frame illustration showing the braking system before and after the driver steps on the brake pedal (i.e., separated presentation). The problem with this layout is that the reader has to scan between the words at the bottom of the page and the corresponding part of the illustration at the top of the page—thereby creating extraneous processing. In contrast, suppose each sentence is moved next to the part of the illustration it describes; for example, "A piston moves forward in the master cylinder" is put next to the master cylinder in the frame showing when the driver steps on the brake pedal, and so on (i.e., integrated presentation). In 5 of 5 tests, involving paper-based lessons on brakes and lightning and computer-based lessons on lightning, learners who received integrated presentations performed better on transfer tests than did students who received separated presentations (Mayer, 1989, Experiment 2; Mayer, Steinhoff, Bower, & Mars, 1995, Experiments 1, 2, and 3; Moreno & Mayer, 1999, Experiment 1). The effect size was 1.12, which is a large effect. As shown on the fourth line of Table 1, the *spatial contiguity principle* is that people learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen.

Finally, consider a narrated animation on how a bicycle tire pump works in which the words in the narration are spoken at the same time as the corresponding action is depicted in the animation; for example, as the narrator says, "When the handle is pulled up," the animation shows the handle moving up (i.e., simultaneous presentation). In contrast, the narration could be presented followed by the animation or vice versa (i.e., successive presentation). The rationale for successive presentation is that it allows the learner to have two separate exposures to the explanation rather than one. However, according to the cognitive theory of multimedia learning, learners must have corresponding words and images in working memory at the same time in order to make connections between them, so simultaneous presentation should result in better learning than successive presentation. As predicted, in 8 out of 8 experiments involving computer-based lessons on pumps, brakes, lungs, and lightning, learners performed better on answering transfer questions when they received simultaneous presentation of animation and narration rather than successive presentation (Mayer & Anderson, 1991, Experiments 1 and 2a; Mayer & Anderson, 1992, Experiments 1 and 2; Mayer, Moreno, Boire, & Vagge, 1999, Experiments 1 and 2; Mayer & Sims, 1994, Experiments 1 and 2). The me-

Table 2
Three Evidence-Based and Theoretically Grounded Principles for Managing Essential Processing

Principle	Definition	Effect Size (*d*)	Number of Tests
Segmenting	Present animation in learner-paced segments.	0.98	3 of 3
Pretraining	Provide pretraining in the name, location, and characteristics of key components.	0.85	5 of 5
Modality	Present words as spoken text rather than printed text.	1.02	17 of 17

dian effect size was 1.31, which is considered a large effect. As shown in the bottom line of Table 1, the *temporal contiguity principle* is that people learn better when corresponding narration and animation are presented simultaneously rather than successively.

In summary, Table 1 lists five techniques for how to reduce extraneous processing: the coherence principle (i.e., eliminate extraneous material), the signaling principle (i.e., highlight essential material), the redundancy principle (i.e., present pictures and spoken words rather than pictures, spoken words, and printed words), the spatial contiguity principle (i.e., place printed text next to the corresponding part of the graphic), and the temporal contiguity principle (i.e., present corresponding graphics and words at the same time).

Three Principles for Managing Essential Processing

Even if one could eliminate extraneous processing, the demands of essential processing could overwhelm the learner when the material is too complex. Complexity is determined by the number of elements and the relations between them. For example, an explanation of how lightning storms develop consists of 16 steps and dozens of elements such as warm and cool air, negative and positive particles, and temperatures above and below the freezing level. This amount of detail is needed for even a simplified explanation of how lightning works, but the learner's cognitive system is likely to be overloaded by all this essential material. One can't delete the material because it is needed for the learner to build a coherent mental representation. Table 2 lists three techniques for managing essential processing, which I refer to as the segmenting, pretraining, and modality principles.

In segmenting, a continuous narrated animation such as the lightning lesson (i.e., continuous presentation) is broken into 16 segments, each consisting of one or two sentences of narration along with about 8 to 10 s of animation (i.e., segmented presentation). At the end of each segment, a "CONTINUE" button appears at the bottom-right side of the screen. When the learner clicks the button, the next segment is presented. According to the cognitive theory of multimedia learning, segmenting allows the learner to fully represent each part of the lightning system before moving on to the next part. In 3 out of 3 experiments, involving computer-based lessons on lightning and electric motors, learners who received segmented lessons performed better on transfer tests than did learners who received continuous lessons (Mayer & Chandler, 2001, Experiment 2; Mayer, Dow, & Mayer, 2003, Experiments 2a and 2b). The median effect size was 0.98, which is a large effect. As shown in Table 2, the *segmenting principle* is that people learn better when a narrated animation is presented in learner-paced segments rather than as a continuous presentation.

In pretraining, one can take, for example, a narrated animation on how a car's braking system works (i.e., no pretraining), and add a pre-lesson that gives the name, location, and characteristics of each component (i.e., pretraining). For example, the main components mentioned in the narrated animation are the brake pedal, the piston in the master cylinder, the fluid in the brake tube, the smaller pistons in the wheel cylinders, the brake shoe, and the brake drum. In the pretraining, learners see the name of each component linked to the location of the component on a graphic of the braking system, and they see the behavior of each component individually; for example, they see an animation of the piston moving forward and back in the master cylinder. Pretraining is intended to manage essential processing during the presentation of narrated animation. The theoretical rationale is that learners who are already familiar with the names, locations, and behavior of each component can devote more of their cognitive capacity to building a cause-and-effect model of the system. In 5 of 5 experiments, involving computer-based lessons on brakes, pumps, and geology, pretrained learners outperformed nonpretrained learners on transfer tests (Mayer, Mathias, & Wetzell, 2002, Experiments 1, 2, and 3; Mayer, Mautone, & Prothero, 2002, Experiments 2 and 3). The median effect size was 0.85, which is a large effect. As summarized in the second line of Table 2, the *pretraining principle* is that people learn better from a narrated animation when they already know the names and characteristics of essential components.

Finally, the third technique for managing essential processing listed in Table 2 is the modality principle. According to the *modality principle*, people learn better from

Table 3
Two Evidence-Based and Theoretically Grounded Principles for Fostering Generative Processing

Principle	Definition	Effect Size (*d*)	Number of Tests
Multimedia	Present words and pictures rather than words alone.	1.39	11 of 11
Personalization	Present words in conversational style rather than formal style.	1.11	11 of 11

graphics with spoken text rather than graphics with printed text. The theoretical rationale is that when text is printed on the screen, learners experience *split attention*—when they are looking at the words they cannot look at the animation, and when they look at the animation they cannot look at the words. The incoming essential information can overload the visual channel. According to the cognitive theory of multimedia learning, the solution is to present the words in spoken form, thereby offloading the processing of the words from the visual channel to the verbal channel. In 17 of 17 experiments, involving computer-based multimedia lessons on lightning, brakes, an aircraft fuel system, environmental science, biology, and electric motors, learners scored higher on transfer tests when the words were presented in spoken form rather than printed form (Harskamp, Mayer, Suhre, & Jansma, 2007, Experiments 1 and 2a; Mayer, Dow, & Mayer, 2003, Experiment 1; Mayer & Moreno, 1998, Experiments 1 and 2; Moreno & Mayer, 1999, Experiments 1 and 2; Moreno & Mayer, 2002b, Experiments 1a, 1b, 1c, 2a, and 2b; Moreno, Mayer, Spires, & Lester, 2001, Experiments 4a, 4b, 5a, and 5b; O'Neil et al., 2000, Experiment 1). The median effect size was 1.02. As can be seen in Table 2, the modality principle has the most support of any of the principles we have investigated. The modality principle helps manage essential processing by offloading cognitive processing from the visual channel—which is overused—to the verbal channel—which is underused.

In summary, Table 2 lists three techniques for managing essential processing: the segmenting principle (i.e., break a continuous lesson into learner-paced parts), the pretraining principle (i.e., provide pretraining on the names, locations, and characteristics of key concepts), and the modality principle (i.e., present graphics with spoken text rather than graphics with printed text).

Two Principles for Fostering Generative Processing

Suppose one is successful in reducing extraneous processing and managing essential processing. As a result, the learner has cognitive capacity available for generative processing. How can one induce learners to engage in generative processing rather than to simply not use the processing capacity they have available? Table 3 lists two techniques intended to foster generative processing in learners—the multimedia principle and the personalization principle.

First, according to the *multimedia principle*, people learn better from words and pictures than from words alone. Why would adding appropriate graphics to a text help people to learn better? According to the cognitive theory of multimedia learning, people learn more deeply when they build connections between a verbal representation and a pictorial representation of the same material. This cognitive process of integration is an important way to promote learner understanding. For example, in a words-only presentation, learners receive a printed text explaining how a pump works; in a words-and-pictures presentation, learners receive the same printed text along with an illustration depicting the pump when the handle is pushed down and pulled up. In 11 of 11 experiments, involving paper-based lessons on brakes, pumps, generators, and lightning and computer-based lessons on brakes, pumps, lightning, and arithmetic, learners who received corresponding graphics with words performed better on transfer tests than learners who received words alone (Mayer, 1989, Experiments 1 and 2; Mayer & Anderson, 1991, Experiment 2a; Mayer & Anderson, 1992, Experiments 1 and 2; Mayer et al., 1996, Experiment 2; Mayer & Gallini, 1990, Experiments 1, 2, and 3; Moreno & Mayer, 1999, Experiment 1; Moreno & Mayer, 2002a, Experiment 1). The median effect size was 1.39, which is a large effect. In short, there is strong and consistent support for designing lessons with words and pictures rather than with words alone.

The second line in Table 3 summarizes the *personalization principle*—the idea that people learn better from a multimedia lesson when words are in conversational style rather than formal style. For example, consider a narrated animation that explains how the human respiratory system works using formal style, in which part of the script is: "During inhaling, the diaphragm moves down, creating more space for the lungs, air enters through the nose or mouth, moves down through the throat and bronchial tubes to tiny air sacs in the lungs." In order to use conversational style, the script could be changed so that each "the" is changed to "your." The theoretical rationale is that personalization techniques—such as using conversational style or polite wording—creates a sense of social partnership with the narrator in which learners try harder to make sense of what their conversational partner is saying. In 11 of 11 experiments, involving computer-based lessons on lungs, lightning, botany, and industrial engineering, learners who received words in conversational style performed better on transfer tests than did learners who received words in formal style (Mayer, Fennell, Farmer, & Campbell, 2004, Experiments 1, 2, and 3; Moreno & Mayer, 2000b, Experiments 1, 2, 3, 4, and 5; Moreno & Mayer, 2004, Experiments 1a and 1b; Wang et al., 2008). The median effect size was 1.11, which is a large effect. Overall there is strong and consistent support for the personalization principle.

In summary, Table 3 lists two techniques for fostering generative processing: the multimedia principle (i.e., present words and pictures rather than words alone) and the personalization principle (i.e., present words in conversational style rather than formal style).

Conclusion

What does it mean to apply psychology to education and training? In this article, I have summarized a program of research on multimedia instruction, which can be considered an example of an application of psychology to education and training. Overall, the 10 principles of multimedia instruction demonstrate the reciprocal relationship between the science of learning and the science of instruction. This reciprocity is reflected in the thesis that understanding how people learn helps researchers identify instructional design features to be tested for effectiveness, and evidence concerning effective (and ineffective) instructional designs can be used to test and improve theories of how people learn.

The tension between basic and applied research has a long and somewhat fruitless history in psychology, including my discipline of educational psychology. The relation between basic and applied research is commonly framed as two ends of a continuum, but a more fruitful way to frame the relation is to see basic and applied research as having overlapping goals. The goal of basic research is to contribute to theory, and the goal of applied research is to contribute to practice. The merging of these two goals yields what Stokes (1997, p. 73) called "use-inspired basic research," what Halpern and Hakel (2002, p. 1) called "applying the science of learning," and what I call *conducting basic research on applied issues*.

My summary of 10 principles of multimedia learning is intended to exemplify the fruitful consequences of merging theoretical goals (i.e., contributing to a science of learning) with practical goals (i.e., contributing to a science of instruction). In my opinion, it does not make sense to distinguish between basic and applied research as mutually exclusive activities. Rather, it appears that it is possible—and fruitful—to conduct basic research on applied problems. In the case of my and my colleagues' research program on multimedia instruction, applying psychology to education and training is a reciprocal activity. It is reciprocal in the sense that a theory of learning must be able to account for what works and doesn't work in authentic instructional situations, and instructional principles must be consistent with what is known about how people learn. By maintaining overlapping theoretical and practical goals, researchers can derive instructional principles that are both grounded in theory and supported by evidence from authentic tasks. In short, success in applying the science of learning occurs when good basic research and good applied research are the same thing.

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