Multimedia Instruction

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Abstract

Multimedia instruction consists of instructional messages that contain words (such as printed or spoken text) and pictures (such as illustrations, diagrams, photos, animation, or video). The rationale for multimedia instruction is that people can learn more deeply from words and pictures than from words alone. Multimedia instruction began with the publication of Comenius' Orbis Pictus (The World in Pictures) in the 1600s, and has progressed to a wide array of computer-based multimedia learning experiences that are available anytime and anywhere. The science of learning—that is, a research-based account of how people learn—is necessary for designing effective multimedia instruction. Meaningful multimedia learning occurs when the learner engages in appropriate cognitive processing during learning, including attending to relevant words and pictures, organizing words and pictures into coherent representations, and integrating the representations with each other and with knowledge activated from long-term memory. Successful instructional methods for improving learning with multimedia include research-based principles for reducing extraneous processing during learning, managing essential processing during learning, and fostering generative processing during learning.

Keywords

Multimedia learning • Science of learning • Extraneous processing • Essential processing • Generative processing

Introduction

What Is Multimedia Instruction?

Multimedia instruction is instruction that includes words (e.g., printed or spoken text) and pictures (i.e., static graphics such as illustrations, diagrams, charts, maps, and photos, or dynamic graphics such as animation and video). Multimedia instruction can be presented on paper (e.g., as printed text and figures), on a computer (e.g., as narrated animation or annotated graphics), on a handheld device (e.g., as a game involving printed words and graphics), or face-to-face (e.g., as a narrated slide presentation). For example, Fig. 31.1 presents an annotated diagram aimed at explaining how a car's braking system works, and Fig. 31.2 presents frames from a narrated animation aimed at explaining how a car's braking system works.

Rationale for Multimedia Instruction

The rationale for multimedia instruction is that people can learn more deeply from words and pictures than from words alone—a finding that has been called the *multimedia principle* (Fletcher & Tobias, 2005; Mayer, 2009). For example,

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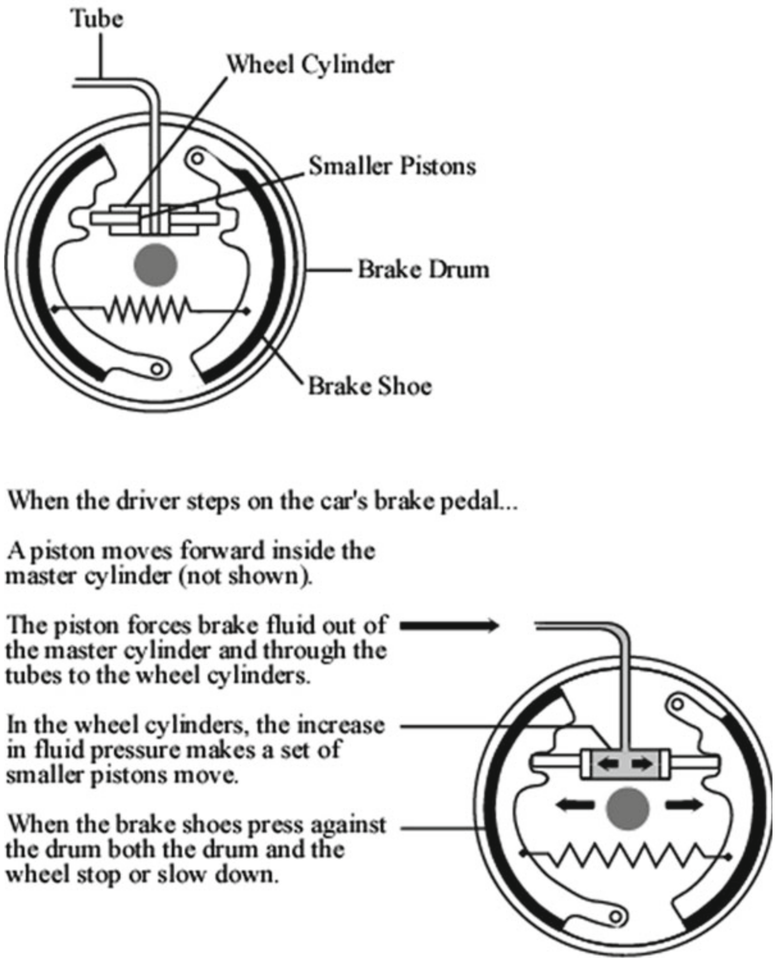

When the driver steps on the car's brake pedal...

A piston moves forward inside the master cylinder (not shown).

The piston forces brake fluid out of the master cylinder and through the tubes to the wheel cylinders.

In the wheel cylinders, the increase in fluid pressure makes a set of smaller pistons move.

When the brake shoes press against the drum both the drum and the wheel stop or slow down.

Fig. 31.1 Annotated diagram of a car's braking system

students who received text and illustrations explaining how a car's braking system works (such as in Fig. 31.1) performed better on a subsequent transfer test than students who received only the printed text (Mayer, 1989; Mayer & Gallini, 1990). Similarly, students who received a narrated animation explaining how a car's braking system works (such as in Fig. 31.2) performed better on a subsequent transfer test than students who received only narration (Mayer & Anderson, 1992). In short, under some circumstances, there is strong and consistent evidence that learning is improved when corresponding graphics are added to words (Mayer, 2009).

Not all multimedia lessons are equally effective, however, so research is needed to determine evidence-based principles for effective multimedia instruction. Some of these design principles are described in the third section of this chapter, and the underlying theory is described in the second section of this chapter.

Historical Overview of Multimedia Instruction

In the field of education, instruction has traditionally been based on verbal media, including spoken words (e.g., in lectures, discussions, or tutorials) and printed words (e.g., in textbooks). Yet over the past 350 years there have been visionaries who proposed an instructional approach that combined words and pictures, and scientists who investigated the effectiveness of such multimedia instruction for student learning.

The history of multimedia instruction has involved three major phases—the introduction of instructional illustrations beginning in the mid-1600s, the scientific study of learning with illustrations and text beginning in the mid-1900s, and the scientific study of multimedia learning in computer-based environments beginning in the late 1900s. The first phase is exemplified by the publication of John Comenius' *Orbis Pictus* ("The World in Pictures") in 1658—the world's first illustrated textbook. Each page consisted of an illustration of some aspect of the world ranging from birds of the field to bones of the human body to a bakery shop to a school, with a number next to each object in the illustration, along with a legend that gave the name and definition of each numbered object in Latin and in the student's native language. The editor of an English-language version of *Orbis Pictus* notes that "it was the first picture-book made for children and was for more than a century the most popular textbook in Europe" (Comenius, 1887).

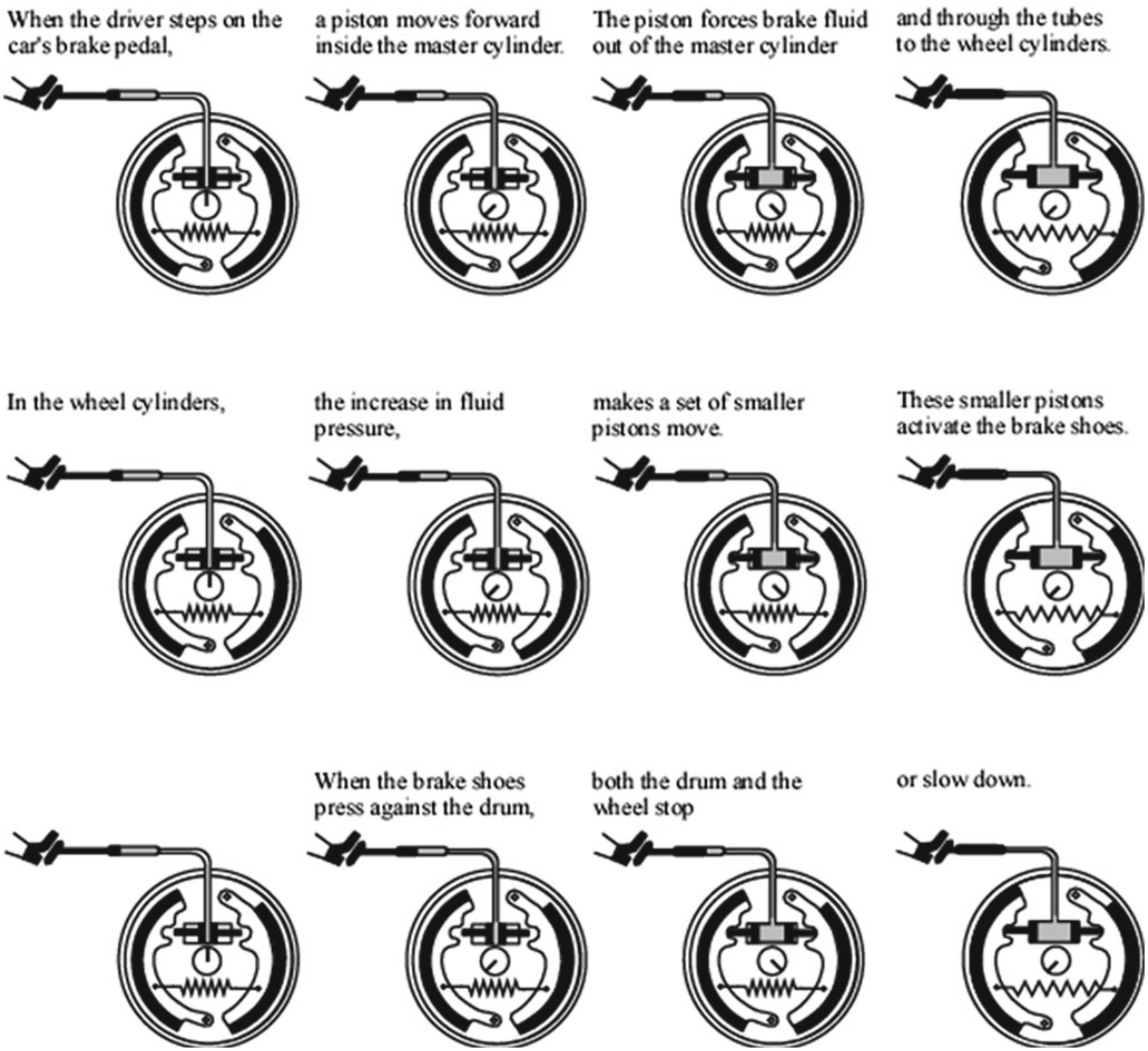

Fig. 31.2 Slides from a narrated animation of a car's braking system

In the field of engineering, machine books containing annotated illustrations of machines began appearing in the middle ages as a means of communicating between engineers and investors as well as between engineers and the artisans carrying out the work (Lefevre, 2004). In the field of business, William Playfield introduced the world's first books to use statistic graphics in 1786 and 1801 (Playfair, 2005), which revolutionized the way statistical information is communicated (Cleveland, 1985; Few, 2004; Kosslyn, 2006; Tufte, 2001).

Orbis Pictus, and other early books involving text and illustrations, can be seen as forerunners of today's textbooks, which devote up to half their space with graphics, though not as effectively as *Orbis Pictus* (Levin & Mayer, 1993; Mayer, Sims, & Tajika, 1995). Advances in technology enabled the spread of multimedia instruction in educational films in the 1920s, educational television in the 1950s, and computer-based instruction in the 1960s (Cuban, 1986). More recent advances in visualization technology have enabled the spread of multimedia instruction in e-learning environments (Clark & Mayer, 2008).

The second major phase in multimedia instruction involves the scientific study of how people learn with printed words and illustrations, which became popular in the mid-to-late 1900s (Flemming & Levie, 1993; Mandl & Levin, 1989; Moore & Dwyer, 1994; Paivio, 1971, 1986; Schnotz & Kulhahy, 1994; Willows & Houghton, 1987). For example, in a rigorous meta-analysis of the learning effects of adding illustrations to printed text, Levin, Anglin, and Carney (1987) reported a large effect size when the illustrations were designed to promote deep cognitive processing (with effect sizes greater than $d = 0.50$) but not when they served mainly to decorate the page (with effect sizes below $d = 0.00$). An important accomplishment of this work was the distinction between visual and verbal channels for processing information as depicted in Paivio's (1971, 1986) dual coding theory as well as preliminary design principles for using illustrations and text (Flemming & Levie, 1993; Moore & Dwyer, 1994).

The third major phase in multimedia instruction, which began in the late 1900s, extends the scientific study of how people learn to include computer-based multimedia instruction. For example, computer-based environments that support multimedia instruction include slide presentations, computer-based training, online multimedia lessons, narrated animation, hypermedia, interactive simulations, intelligent tutoring systems, animated pedagogical agents, virtual reality, and serious games (Atkinson, 2008; Clark & Mayer, 2008; Graesser, Chipman, & King, 2008; Kosslyn, 2007; Lowe & Schnotz, 2008). This third phase in multimedia instruction has both a theoretical goal of contributing to the science of learning by developing a cognitive theory of multimedia learning and a practical goal of contributing to the science of instruction by developed evidence-based principles for the design of multimedia instruction (Clark & Mayer, 2008; Mayer, 2005, 2009). The remainder of this chapter summarizes the progress being made in achieving these goals of building a theory of how people learn from multimedia instruction and compiling principles of multimedia instructional design.

Applying the Science of Learning to Multimedia Instruction

How Multimedia Learning Works

The science of learning is the scientific study of how people learn, that is, how the learner's experience causes a change in the learner's knowledge (Mayer, 2008, 2011). When applied to multimedia instruction, the goal is to understand how people learn from words and pictures. Three relevant principles about the human information processing system derived from research in cognitive science are as follows:

Dual channels—people have separate channels for processing verbal and pictorial material (Paivio, 1986, 2001)

Limited capacity—people can process only a few pieces of information in each channel at any one time (Baddeley, 1986, 1999; Sweller, 1999)

Active processing—meaningful learning occurs when people engage in appropriate cognitive processing during learning, including attending to the relevant information, mentally organizing it into coherent structures, and integrating it with other structures and with knowledge activated from long term memory (Mayer, 2009; Mayer & Wittrock, 2006; Wittrock, 1989)

Figure 31.3 presents a model of how multimedia learning works based on the cognitive theory of multimedia learning (Mayer, 2008, 2011; Mayer & Moreno, 2003). The model consists of two channels (i.e., a verbal channel on top and pictorial channel on the bottom), three memory stores (i.e., sensory memory, working memory, and long-term memory represented as boxes), and five cognitive processes represented as arrows (i.e., selecting words, selecting images, organizing words, organizing images, and integrating).

The learning process begins when the learner receives a multimedia instructional message—such as when the learner reads an illustrated textbook, attends a PowerPoint lecture, clicks on an online narrated animation, or plays an educational computer game. Spoken words and sounds impinge on the ears, resulting in their sounds being held in auditory sensory memory for a very brief period (i.e., <1 s); pictorial material and printed words impinge on the eyes, resulting in their images being held in visual sensory memory for a very brief period (i.e., <1 s). If the learner attends to the incoming sounds and images (indicated by the *selecting words* arrow and the *selecting images* arrow, respectively), some of the information is transferred for additional processing to working memory (which has limited capacity in each channel). In working memory, as indicated by the *organizing words* arrow, the learner arranges the incoming sounds into a coherent cognitive representation, which can be called a *verbal model*;

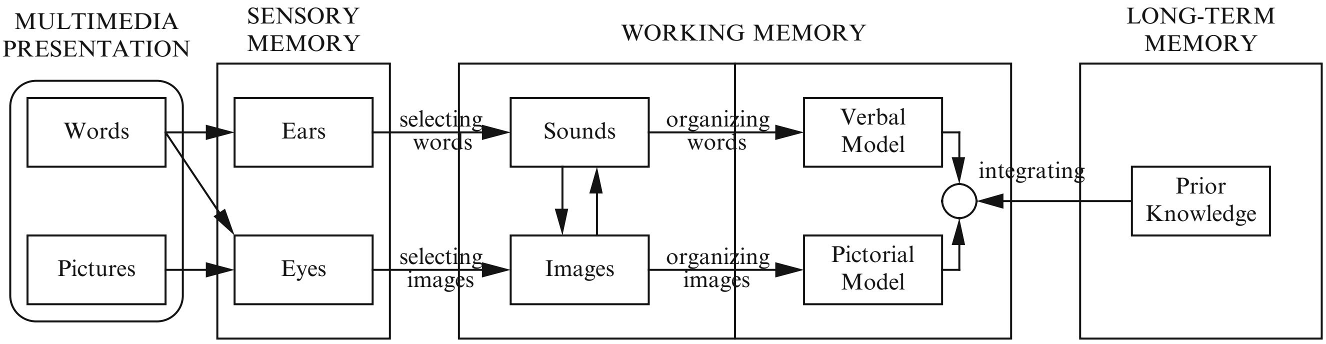

Fig. 31.3 A cognitive theory of multimedia learning

Table 31.1 Three demands on the learner's cognitive capacity during learning

Type	Definition	Cause	Arrows
Extraneous processing	Cognitive processing that does not serve the instructional goal	Poor instructional design	None
Essential processing	Cognitive processing for building a mental representation of the presented material as presented	Complexity of the material	Selecting (and initial organizing)
Generative processing	Cognitive processing aimed at making sense of the presented material	Learner's motivation to exert effort to learn	Organizing and integrating

and as indicated by the *organizing images* arrow, the learner arranges the incoming images into a coherent cognitive representation, which can be called a *pictorial model*. Finally, as indicated by the *integrating arrow*, the learner builds connections between corresponding aspects of the verbal and pictorial models and with relevant prior knowledge activated from long-term memory (which contains the learner's storehouse of knowledge). Once the knowledge is constructed in working memory, the learner can embed it in long-term memory for permanent storage. The learning process depicted in Fig. 31.3 also depends on the learner's motivation to want to make sense of the presented material and the learner's metacognition with respect to selecting, monitoring, and controlling appropriate cognitive processing during learning.

How to Design Multimedia Instruction that Fosters Multimedia Learning

The model of multimedia learning includes five cognitive processes for meaningful learning from multimedia instruction, as indicated by the five arrows in Fig. 31.3. Guiding these cognitive processes during learning is the primary focus of multimedia instruction. The major challenge for designing effective multimedia instruction is that meaningful learning requires that the learner engages in appropriate cognitive processing during learning, but the learner's capacity for processing information in each channel in working memory is extremely limited.

Drawing on Sweller's (1999, 2005; Brunken, Plass, & Moreno, 2010) cognitive load theory and Mayer's (2009; Mayer & Moreno, 2003) cognitive theory of multimedia learning, Table 31.1 lists three kinds of demands on the learner's cognitive processing capacity during learning. Extraneous processing is cognitive processing during learning that does not serve the instructional goal, and is caused by poor instructional design. For example, in a situation where an illustration is on one page and the text describing it is on a different page, the learner must engage in scanning back and forth between the corresponding words and graphics, which results in extraneous processing. Therefore, an important instructional goal is to design multimedia instruction in ways that reduce extraneous processing.

Essential processing is cognitive processing during learning that is required to mentally represent selected parts of the presented material as they were presented, and is caused by the inherent complexity of the material. For example, in a situation where a novice is learning a complicated concept, such as how a lightning storm develops, a great amount of cognitive processing is required to mentally represent the material. Therefore, an important instructional goal is to design multimedia instruction in ways that manage essential processing.

Generative processing is cognitive processing during learning aimed at making sense of the presented material by processing it more deeply, and is caused by the learner's motivation to exert effort to understand the material. For example, learners may explain a lesson to themselves, looking for inconsistencies with their prior knowledge. Therefore, an important instructional goal is to design multimedia instruction in ways that foster generative processing.

According to this triarchic theory, instructional designers must deal with situations in which learning tasks place three kinds of cognitive processing demands on learners (i.e., heavy processing demands) but learners possess limited capacity for cognitive processing during learning (i.e., limited processing capacity). Figure 31.4 summarizes three multimedia instruction scenarios, each requiring a different kind of multimedia instructional design solution.

In the extraneous overload situation (shown in the top of Fig. 31.4), the amount of extraneous, essential, and generative processing required for learning overloads the learner's available cognitive capacity (i.e., the amount of processing the learner can carry out at one time in working memory). If the learners are wasting precious cognitive capacity on extraneous processing, they may not have adequate capacity remaining for essential and generative processing, which are needed for meaningful learning. When an instructional scenario creates excessive extraneous cognitive processing, an important instructional goal is to design the lessons in ways that reduce extraneous processing.

In the essential overload situation (shown in the middle of Fig. 31.4), the need for extraneous processing has been eliminated or greatly reduced, but the amount of required essential processing still exceeds the learner's cognitive capacity. In this case it is not appropriate to reduce essential processing because essential processing is required for the

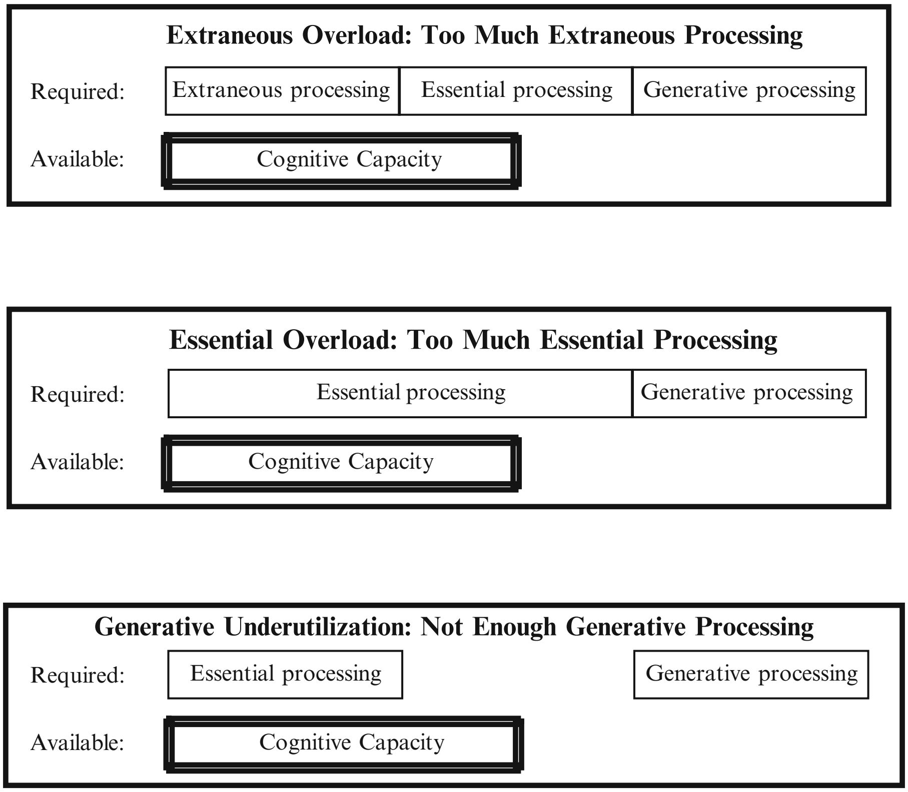

Fig. 31.4 Three demands on the learner's cognitive capacity during learning

learner to mentally represent the presented material (although with growing expertise learners will be able to chunk the incoming information in ways that minimize the demand for essential processing). When an instructional scenario creates excessive essential cognitive processing, an important instructional goal is to manage essential processing.

In the generative underuse situation (shown in the bottom of Fig. 31.4), extraneous load has been eliminated and essential load has been managed so the learner has cognitive capacity to engage in generative processing but chooses not to do so. In this case, an important instructional goal is to foster generative processing by designing instruction in ways that encourage the learner to engage in deeper processing (e.g., organizing and integrating) during learning.

Research-Based Principles of Multimedia Instruction

The triarchic theory suggests three instructional goals, each for a different instructional scenario—reduce extraneous processing for extraneous overload situations, manage essential processing for essential overload situations, and foster generative processing for generative underuse scenarios. This section explores some evidence-based principles for accomplishing each of these three goals. Most principles are based on research evidence as documented in one of three sources: (1) a handbook of research on multimedia learning (Mayer, 2005), (2) an Association for Psychological Science task force report on research-based learning principles applicable to education (Halpern, Graesser, & Hakel, 2007), and (3) a report issued by the US Department of Education on research-based learning principles applicable to education (Pashler et al., 2007). This section focuses on principles that consistently generate effect sizes greater than $d = 0.40$, which Hattie (2009) argues is the level needed for practical relevance for education.

Principles for Reducing Extraneous Processing

Table 31.2 lists six principles for reducing extraneous processing—coherence, signaling, spatial contiguity, temporal contiguity, redundancy, and expectation principles.

The *coherence principle* is that people learn better from a multimedia lesson when extraneous material is excluded rather than included. For example, in a series of six experiments involving a multimedia lesson on lightning formation including both paper-based formats (Harp & Mayer, 1997, 1998) and computer-based formats (Mayer, Heiser, & Lonn, 2001) students performed better on a transfer posttest if they learned from a concise presentation than from an elaborated

Table 31.2 Evidence-based principles for reducing extraneous processing

Principle	Description	Example
Coherence (Halpern et al., 2007; Mayer, 2005)	Eliminate extraneous words and pictures	Cut out interesting but irrelevant anecdotes and cartoons
Signaling (Mayer, 2005)	Highlight essential words and pictures	Use an outline and headings; put key terms in bold font for a text lesson
Spatial contiguity (Halpern et al., 2007; Mayer, 2005; Pashler et al., 2007)	Place text next to the part of the graphic it describes	Embed each part of a caption next to the corresponding part of an illustration
Temporal contiguity (Halpern et al., 2007; Mayer, 2005)	Present corresponding graphics and spoken text at the same time	In a narrated animation, describe the events in audio at the same time they are depicted on the screen
Redundancy (Mayer, 2005)	Present graphics with spoken words rather than graphics with spoken and printed words	Do not add onscreen text to a narrated animation
Expectation (Halpern et al., 2007)	Present a preview of the test items or instructional objectives before the lesson	Before this section of the chapter, present the question: "What are the names, definitions, and examples of six principles for reducing extraneous processing?"

presentation containing added sentences, photos, or video clips that were interesting but not relevant to the explanation. The median effect size was $d=1.66$, which is large effect. In a follow-up study, students received a PowerPoint presentation on how a virus causes someone to catch a cold or on how the human digestive system works, which included inserted statements about the topic that were high or low in interest (Mayer, Griffith, Naftaly, & Rothman, 2008); the study showed that the low-interest group outperformed the high-interest group on a transfer posttest, with $d>0.80$ in both experiments.

Overall, these results are consistent with previous research showing that student learning from text is diminished when the text contains added *seductive details*—interesting but irrelevant sentences, such as amusing anecdotes or grizzly facts (Garner, Brown, Sanders, & Menke, 1992; Hidi & Baird, 1986; Mohr, Glover, & Ronning, 1984; Shirey, 1992; Shirey & Reynolds, 1988; Wade, 1992; Wade & Adams, 1990). For example, in a replication involving a text lesson on lightning formation, Lehman, Schraw, McCrudden, and Hartley (2007) found that adding interesting but extraneous sentences about lightning throughout a lesson resulted in significantly less learning ($d=0.88$) based on deep processing measures such as a holistic understanding score for student essays.

Adding background music or environmental sounds to a narrated animation on lightning or brakes also resulted in lowered transfer posttest performance, with a median effect size of $d=1.11$ based on two experiments (Moreno & Mayer, 2000a). Adding relevant factual or mathematical details to a multimedia lesson on how lightning works or how ocean waves work that are not needed to understand how the basic cause-and-effect system works also resulted in lowered transfer test performance, yielding a median effect size of $d=0.82$ across six experiments (Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer & Jackson, 2005). Overall, there is strong and consistent evidence for the coherence principle based on well-controlled laboratory studies. The effect may be diminished for high knowledge learners (Ploetzner, Fehse, Kneser, & Spada, 1999) or for high working memory capacity learners (Sanchez & Wiley, 2006).

The *signaling principle* is that people learn better when the essential material and its organization are highlighted. Verbal signaling can take the form of putting essential printed text in bold font (or giving vocal emphasis to essential spoken text), adding an outline or graphic organizer containing the same words as in the text, adding headings that correspond to the outline, or including pointer words such as "first…second…third." Visual signaling can take the form of adding arrows, flashing, or a spotlight that grays out the nonessential areas. In a series of six experiments involving paper-based multimedia lessons on lightning or biology (Harp & Mayer, 1998; Stull & Mayer, 2007) and computer-based narrated animations on how airplanes achieve lift (Mautone & Mayer, 2001), students performed better on a transfer posttest when the presentation included verbal signals, yielding a median effect size of $d=0.52$. These results help extend earlier research on learning from text showing that verbal signaling improves students' retention of a text passage (Loman & Mayer, 1983; Lorch, 1989; Lorch & Lorch, 1996; Lorch, Lorch, & Inman, 1993; Meyer, 1975; Meyer, Brandt, & Bluth, 1980).

Visual signaling involving arrows was not found to be effective in promoting transfer posttest performance with animations on how airplanes achieve lift (Mautone & Mayer, 2001) and on how a toilet tank flushes (Hegarty & Kriz, 2007). In some cases transfer test performance was improved when online multimedia lessons included an onscreen agent who pointed to essential material in a worked example (Atkinson, 2002), when the appropriate portion of a worked example flashed on the screen as a narrator described it (Jeung, Chandler, & Sweller, 1997), and when spreading color was used to indicate the flow of activity in narration on piano mechanisms (Boucheix & Lowe, 2010). Spotlighting the appropriate portion of a narrated animation on the human heart as the narrator described it (by decreasing luminance outside the spotlight) improved transfer performance in one study (de Koning, Tabbers, Rikers, & Paas, 2007) but not in another (de Koning, Tabbers, Rikers, & Paas, 2010). Overall, there is moderate evidence for the benefits of verbal signaling but continuing research is needed to establish principles for visual signaling. The effect may be diminished for high-knowledge learners (Meyer et al., 1980; Naumann, Richter, Flender, Cristmann, & Groeben, 2007) or when the material is simple for the learner (Jeung et al., 1997).

The *spatial contiguity principle* states that people learn better when corresponding printed words and graphics are presented near each other on the page or screen. In a core set of five experiments carried out in our lab involving paper-based multimedia lessons on brakes and lightning (Mayer, 1989; Mayer, Steinhoff, Bower, & Mars, 1995) and a computer-based multimedia lesson on lightning (Moreno & Mayer, 1999a), students performed better on a transfer posttest if words describing each step in the process were placed next to the portion of the diagram they described rather than as a caption at the bottom of the diagram, with a median effect size of $d=1.12$.

Similar results favoring integrated presentation over separated presentation of printed words and graphics were found with paper-based lessons on mathematics (Sweller, Chandler, Tierney, & Cooper, 1990), engineering (Chandler & Sweller, 1991, 1992; Tindall-Ford, Chandler, & Sweller, 1997), and how the heart works (Chandler & Sweller, 1991), and with computer-based lessons on how a tire pump works (Bodemer, Ploetzner, Feuerlein, & Spada, 2004), statistics (Bodemer et al., 2004), and physics (Kester, Kirschner, & van Merrienboer, 2005). In a recent meta-analysis of 37 experiments on spatial contiguity, Ginns (2006) reported an average effect size of $d=0.71$ favoring integrated over separated presentation, and the effect size was $d=1.07$ for published studies that used posttest measures of transfer.

Overall, there is strong and consistent evidence for the spatial continuity principle involving both paper-based and computer-based multimedia lessons. The effect may be diminished for high-knowledge learners (Mayer et al., 1995), when the material is very simple for the learner (Ayres & Sweller, 2005), or when the graphic can be understood without accompanying words (Ayres & Sweller, 2005).

The *temporal contiguity principle* is that people learn better when corresponding spoken text and graphics are presented simultaneously rather than successively. Across eight computer-based experiments carried out in our lab, students who received simultaneous presentations (i.e., narration and corresponding animation, video, or slides at the same time) performed better on transfer posttests than students who received successive presentations (i.e., narration before or after animation, video, or slideshow), including multimedia lessons on tire pumps (Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994), brakes (Mayer & Anderson, 1992; Mayer, Moreno, Boire, & Vagge, 1999), lungs (Mayer & Sims, 1994), and lightning (Mayer et al., 1999). The median effect size was $d=1.31$, which is a large effect.

These findings mesh well with classic studies in which students remembered more from a narrated movie on carnivorous plants (Baggett & Ehrenfeucht, 1983) or toy construction (Baggett, 1984) than one in which the sound track was misaligned from the movie. In a recent meta-analysis of 13 experiments on temporal contiguity, Ginns (2006) reported an average effect size of $d=0.87$ on learning outcome measures favoring simultaneous over successive presentation.

Overall, there is strong and consistent evidence for the temporal contiguity principle. The effects may be diminished when learners have control over the pace and order of presentation (Michas & Berry, 2000) and when the segments are very short (Mayer et al., 1999; Moreno & Mayer, 1999a).

The *redundancy principle* is that people learn better from graphics with spoken words than from graphics with redundant spoken and printed words. In a set of five computer-based studies involving lightning (Mayer et al., 2001; Moreno & Mayer, 2002a) and an environmental science game (Moreno & Mayer, 2002b), students who received a narrated animation (or narrated slideshow) performed better on a transfer posttest than students who received the identical presentation with on-screen text added as captions. The median effect size was $d=0.72$.

Similar results yielding similar effect sizes were obtained with computer-based lessons involving human memory (Jamet & Le Bohec, 2007), lightning (Craig, Gholson, & Driscoll, 2002), and electrical engineering (Kalyuga, Chandler, & Sweller, 1999, 2000) as well as paper-based lessons on temperature graphs (Leahy, Chandler, & Sweller, 2003) and math problems (Mousavi, Low, & Sweller, 1995). In a recent review, Sweller (2005) used a somewhat broader definition of redundancy, but also concluded that there was empirical support for the redundancy principle.

Overall, there is strong and consistent evidence for the negative consequences of adding redundant onscreen text to a narrated animation, video, or slideshow. The redundancy effect may be diminished when the onscreen text is shorted to a few key words that are placed next to the corresponding part of the graphic (Mayer & Johnson, 2008). When there are no graphics, presenting concurrent spoken and printed text can result in better learning than printed words alone when the verbal segments are short (Moreno & Mayer, 2002a) but not when they are long (Diao & Sweller, 2007).

The *expectation principle* is that people learn better when they are shown the type of test items in advance of the lesson. For example, when Mayer, Dow, and Mayer (2003) presented sample pre-questions before a narrated animation on electric motors, students performed better on a transfer posttest (with different transfer questions) than when students did not receive pre-questions, with an effect size of $d=0.83$.

Table 31.3 Evidence-based principles for managing essential processing

Principle	Description	Example
Segmenting (Halpern et al., 2007; Mayer, 2005)	Break a complex lesson into manageable parts	Break a continuous narrated animation into small segments, each controlled by an onscreen "Continue" button
Pretraining (Mayer, 2005)	Before a lesson, provide training in the names and characteristics of key elements	Tell people the name, location, and actions of each part in braking system before showing a narrated animation on how brakes work
Modality (Mayer, 2005; Pashler et al., 2007)	Present graphics with spoken text rather than with printed text	Present a narrated animation on lightning rather than an animation with onscreen captions

This finding meshes with classic research on adjunct questions in learning from text, in which pre-questions produced positive effects on retention (Boker, 1974; Rothkopf, 1966; Rothkopf & Bisbicos, 1967). Overall, there is promising initial support for the expectation principle, but more research is needed, including additional research on providing students with a statement of the instructional objective.

Principles for Managing Essential Processing

Table 31.3 lists three principles for managing essential processing—segmenting, pretraining, and modality principles. The *segmenting principle* is that people learn better when a complex lesson is presented in manageable parts. Learners can fully digest one segment of the lesson before moving on to the next segment. For example, Mayer and Chandler (2001) found that compared to viewing a continuous 2.5 min narrated animation on lightning formation, students performed better on a transfer test after viewing a narrated animation on lightning formation that paused after each of 16 segments until the learner clicked a "Continue" button. Similarly, compared to viewing continuous narrated animation on how an electric motor works, students performed better on a transfer test in two experiments if they could see the presentation broken into five segments, each started by the learner's mouse click (Mayer et al., 2003). Overall, across three experiments conducted in our lab, the median effect size across these three experiments was $d=0.98$, favoring the segmented group over the continuous group.

Similar results were obtained in which students learned better when worked-out examples were broken into manageable steps for solving probability problems (Gerjets, Scheiter, & Catrambone, 2006) and for solving algebra equations (Ayres, 2006), and in which students learned better when a complex graph was broken into parts (Lee, Plass, & Homer, 2006; Mautone & Mayer, 2007). Overall, there is a growing base of support for the segmenting principle, with a median effect size of $d=0.82$ across nine experiments. Concerning boundary conditions, Ayres (2006) provides some evidence that the effects of segmenting may be strongest for low-knowledge learners.

According to the *pretraining principle*, people learn better from a complex lesson when they receive pretraining in the names and characteristics of the key concepts. Less processing is required when the complex lesson is presented because the learner already knows about the key concepts. In a core set of five experiments carried out in our lab, students performed better on a transfer test when a narrated animation on brakes (Mayer, Mathias, & Wetzell, 2002) or tire pumps (Mayer et al., 2002) or a geology game about geology formations (Mayer, Mautone, & Prothero, 2002) was preceded by a brief introduction to the names and characteristics of each key component of the system. The median effect size was $d=0.85$, which is considered to be a large effect. Similar results with large effect sizes were obtained in computer-based lessons on statistics (Kester, Kirschner, & van Merrienboer, 2004) and electronics (Kester, Kirschner, & van Merrienboer, 2006), as well as paper-based lessons on electrical engineering (Pollock, Chandler, & Sweller, 2002) and mathematics (Clarke, Ayres, & Sweller, 2005). Overall, there is strong and consistent evidence for the pretraining principle across ten experiments, yielding a median effect size of $d=0.88$. Concerning boundary conditions, preliminary evidence suggests that the effects of pretraining may be strongest for low knowledge learners (Clarke et al., 2005; Pollock et al., 2002).

The *modality principle* is that people learn better from a multimedia lesson when words are spoken rather than printed. Removing printed words from the page or screen frees up capacity in the visual channel allowing more processing of the graphics, and providing spoken words offloads some on the processing demands onto the verbal channel, which has capacity available. In a set of 17 experiments on modality, my colleagues and I have found strong and consistent evidence that learners perform better on transfer tests when words in a multimedia lesson are spoken (as narrated graphics, for example) rather than printed on the screen (as captioned graphics), with a median effect size of $d=1.02$. The findings include computer-based lessons on lightning (Mayer & Moreno, 1998; Moreno & Mayer, 1999a), brakes (Mayer & Moreno, 1998), electric motors (Mayer et al., 2003), and biology (Harskamp, Mayer, Suhre, & Jansma, 2007) as well as an environmental science game (Moreno, Mayer, Spires, & Lester, 2001; Moreno & Mayer, 2002a, 2002b) and an aircraft simulation (O'Neil et al. , 2000).

Similar results with generally strong effect sizes have been reported in paper-based lessons on how to solve geometry

Table 31.4 Evidence-based principles for fostering generative processing

Principle	Description	Example
Multimedia (Halpern et al., 2007; Mayer, 2005; Pashler et al., 2007)	Present words and pictures rather than words alone	Present a narrated animation on lightning rather than a narration
Personalization (Mayer, 2005)	Put words in conversational style	Say "I" and "you" rather than only use third person constructions
Voice	Use human speech rather than machine speech	Use recorded sound files of human voice rather than machine-synthesized voice

problems (Mousavi et al., 1995), how to solve electrical circuit problems (Tindall-Ford et al., 1997), and graph reading (Leahy et al., 2003), as well as computer-based lessons on lightning (Craig et al., 2002), electrical engineering (Kalyuga et al., 1999, 2000), and solving math problems (Atkinson, 2002; Jeung et al., 1997). In contrast to 35 experiments favoring the modality principle, with a median effect size of $d=0.88$, the modality effect was not obtained in a study in which the pace of the lesson was slow and under learner control (Tabbers, Martens, & van Merrienboer, 2004), thereby suggesting a possible boundary condition. In a meta-analysis based on 39 between-subjects comparisons, Ginns (2005) reported a mean effect size of $d=0.72$ favoring the use of spoken words over printed words in multimedia lessons.

Overall, the modality principle has been more widely tested than any other principle, and has achieved a high level of empirical support. Some important boundary conditions that warrant further study include that the modality effect may be stronger when the material is complex (Ginns, 2005; Tindall-Ford et al., 1997), the relevant portion of the graphic is highlighted (Jeung et al., 1997), the words are familiar to learners (Harskamp et al., 2007), and lesson is fast-paced and under system control (Ginns, 2005; Tabbers et al., 2004).

Principles for Fostering Generative Processing

Table 31.4 lists three principles for fostering generative processing—multimedia, personalization, and voice. The *multimedia principle* is that people learn better from words and pictures than from words alone. The rationale is that multimedia presentations encourage learners to build connections between corresponding words and pictures, thereby causing them to engage in one of the key cognitive processes in meaningful learning—the process of integrating. Across 11 experiments conducted in our lab, students performed better on transfer tests when their lesson contained printed words and corresponding illustrations rather than printed words alone (Mayer, 1989; Mayer & Gallini, 1990) or spoken words and corresponding animation rather than spoken words alone (Mayer & Anderson, 1991, 1992; Moreno & Mayer, 1999a, 2002b), yielding a median effect size of $d=1.39$. Similar findings were reported for a computer-based lesson on lightning (Moreno & Valdez, 2005) and for a lecture on learning principles (Moreno & Valdez, 2007; Moreno & Ortegano-Layne, 2008). Overall, there is strong and consistent evidence for the multimedia principle. Some possible boundary conditions are that the multimedia effect may be stronger for low knowledge learners (Kalyuga, Chandler, & Sweller, 1998, 2000; Mayer & Gallini, 1990) and for high-quality graphics (Schnotz & Bannert, 2003).

The *personalization principle* is that people learn better when the instructor uses conversational style rather than formal style. The rationale is that people try harder to make sense of the presented material (i.e., engage in the cognitive processes of organizing and integrating) when they feel they are in a social partnership with the instructor. Across 11 experiments carried out in our lab, students performed better on transfer tests when they received a multimedia lesson in which the words were in conversational style (such as using "you," "I," and "we") rather than formal style, including computer-based lessons on lightning (Moreno & Mayer, 2000b) and the human respiratory system (Mayer, Fennell, Farmer, & Campbell, 2004), and games on environmental science (Moreno & Mayer, 2000b, 2004) and engineering (Wang, Johnson, Mayer, Rizzo, Shaw, & Collins, 2008). The median effect size was $d=1.11$, which is a large effect. The effect also applies to polite wording of feedback and guidance by online tutors in an engineering game (Wang et al., 2008), but was not obtained with online chemistry tutors in classrooms (McLaren, Lim, Gagnon, Yaron, & Koedinger, 2006). Continuing research is needed to pinpoint the conditions most suitable for using conversational or polite wording.

The *voice principle* is that people learn better when an online instructor speaks with a human voice rather than a machine voice. The rationale is that an instructor using a human voice is more readily accepted as a social partner (Nass & Brave, 2005), thereby fostering deeper cognitive processing during learning. In a set of three experiments involving computer-based lessons on lightning formation (Mayer, Sobko, & Mautone, 2003) and mathematics word problems (Atkinson, Mayer, & Merrill, 2005), students performed better on transfer tests when the onscreen agent spoke in a friendly human voice rather than a machine-synthesized voice, yielding a median effect size of $d=0.78$. These results provide promising preliminary evidence for the voice principle, but a larger evidence base is needed. A potential boundary condition concerns the role of the match between the learner's and instructor's gender, race, ethnicity, or emotional state (Nass & Brave, 2005).

Complementary evidence across nine experiments shows that adding the instructor's physical image on the screen (such as a talking head or a motionless cartoon character) does not substantially improve learning (Atkinson, 2002; Craig et al., 2002; Mayer et al., 2003; Moreno et al., 2001), yielding a median effect size of $d = 0.26$. Thus, the available evidence does not provide strong support for what could be called the *image principle* (Mayer, 2009). One possible suggestion may be that the onscreen agent would be more effective if it engaged in human-like gesturing (Goldin-Meadow, 2003; Hostetter, 2011; Lusk & Atkinson, 2007), an intriguing idea that warrants further study and could be called the *embodiment principle*.

Finally, some other candidates for fostering generative processing—also relevant to non-multimedia environments (Mayer, 2011)—are the concretizing principle, the anchoring principle, the testing principle, the self-explanation principle, the worked-out example principle, the guided discovery principle, the questioning principle, and the elaboration principle. The *concretizing principle* is that people learn better when unfamiliar material is presented in a way that relates it with the learner's familiar knowledge, such as using concrete examples and analogies. Research on concrete advance organizers provides encouraging evidence that students learn more deeply from a text lesson when it is preceded with a familiar concrete model or analogy (Mayer, 2008). Research on the use of concrete manipulatives in mathematics instruction offers another source of encouraging evidence (Lillard, 2005). In a multimedia learning environment, for example, allowing students to move an onscreen bunny along a number line helped students learn about addition and subtraction of signed numbers (Moreno & Mayer, 1999b).

The *anchoring principle* is that people learn better when material is presented in the context of a familiar situation, such as embedding a lesson on algebraic functions within the context of running a pizza business (Brenner et al., 1997). Research on multimedia learning also shows that anchoring a mathematics lesson within the narrative of a realistic practical problem can enhance learning (Bransford et al., 1996).

The *testing principle* is that people learn better when they take a practice test on the material have studied. Research using noneducational materials provides promising evidence (Roediger & Karpicke, 2006), as do some preliminary findings using educational multimedia in a computer-based environment (Johnson & Mayer, 2009). The *self-explanation principle* is that people learn better when they are prompted to explain lesson elements during learning, an idea that has preliminary empirical support in multimedia environments (Johnson & Mayer, 2010; Roy & Chi, 2005). The *worked-example principle* is that people learn better when they are shown a step-by-step example of how to solve a problem, with commentary—a principle that has extensive support including some multimedia learning environments (Renkl, 2005, 2011). The *guided discovery principle* is that people learn better when they are allowed to solve problems while receiving appropriate guidance, a technique that has been successful with computer simulation (de Jong, 2005, 2011). The *questioning principle* is that people learn better when they must ask and answer deep questions during learning and the *elaboration principle* is that people learn better when they outline, summarize, or otherwise elaborate on the presented material (Mayer, 2011). Finally, providing high quality feedback has long been recognized as one the most powerful instructional techniques for skill learning (Hattie & Gan, 2011; Shute, 2008), so its role in multimedia instruction warrants further investigation (Ido, Aleven, McLaren, & Koedinger, 2011).

Conclusion

Multimedia instruction involves instructional messages that consist of words (e.g., spoken or printed text) and pictures (e.g., drawings, charts, photos, animation, or video). The science of multimedia learning is concerned with developing a research-based theory of how people learn from words and pictures. Three major principles for a cognitive theory of multimedia learning are that learners have separate information processing channels for verbal and visual material (i.e., dual channel principle), that learners can engage in only a small amount of processing in each channel at any one time (i.e., limited capacity principle), and that meaningful learning depends on the learner's cognitive processing during learning (i.e., active processing principle). The science of multimedia instruction is concerned with developing design principles for multimedia instruction that are consistent with research evidence and grounded in cognitive theory.

Three kinds of goals of multimedia instruction design are to minimize extraneous cognitive processing during learning (i.e., cognitive processing that does not serve the instructional goal), to manage essential processing during learning (i.e., cognitive processing needed to mentally represent the essential material), and to foster generative processing during learning (i.e., cognitive processing aimed at making sense of the material). Research on instructional effectiveness pinpoints the degree to which students perform better on subsequent transfer tests when multimedia instruction is based on instructional design principles. Some principles for reducing extraneous processing during learning are coherence, signaling, redundancy, spatial contiguity, temporal contiguity, and expectation. Some principles for managing essential processing during learning are segmenting, pretraining, and modality. Some principles for fostering generative processing during learning are multimedia, personalization and voice.

A logical next step would be to explore what makes the difference between extraneous processing and generative processing, that is, what determines whether added material is relevant to the instructional goal. In addition, continuing research is needed to determine the boundary conditions for each principle in multimedia instruction, such as the degree to which principles apply to different kinds of learners, learning objectives, and learning contexts.

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