13 Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pre-training, and Modality Principles

Richard E. Mayer
University of California, Santa Barbara

Celeste Pilegard
University of California, Santa Barbara

Abstract

When a concise multimedia lesson containing complicated material is presented at a fast rate, the result can be a form of cognitive overload called *essential overload*. Essential overload occurs when the amount of essential cognitive processing (similar to intrinsic cognitive load) required to understand the multimedia instructional message exceeds the learner's cognitive capacity. Three multimedia design methods intended to minimize essential overload are the segmenting, pre-training, and modality principles. The segmenting principle is that people learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit. This principle was supported in 10 out of 10 experimental tests, yielding a median effect size of 0.79. The pre-training principle is that people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. This principle was supported in 13 out of 16 experimental tests, yielding a median effect size of 0.75. The modality principle is that people learn more deeply from a multimedia message when the words are spoken rather than printed. This principle was supported in 53 out of 61 experimental tests, yielding a median effect size of 0.76.

What Are the Segmenting, Pre-training, and Modality Principles?

Definitions

Consider a multimedia learning situation in which too much essential information is presented at too fast a rate for you to adequately process. For example, when a narrated animation contains a large amount of complicated material that is not familiar to you and comes to you at a fast pace determined by the computer, the result can be a form of cognitive overload called *essential overload*. Essential overload occurs when the amount of essential cognitive processing required by the multimedia instructional message exceeds the learner's cognitive capacity. *Essential processing* (similar to Sweller's *intrinsic cognitive load*; Sweller, Ayres, & Kalyuga, 2011; see also Chapter 2) refers to cognitive processing – such as selecting relevant words and images and organizing them as presented (as described in Chapter 3) – required to represent the essential material.[1] *Cognitive capacity* refers to the total amount of processing that can be supported by both the auditory and visual channels of the learner's working memory at any one time. *Essential material* refers to the words and pictures needed to achieve the instructional objective, such as all words and graphic elements needed for understanding how a lightning storm develops.

To address the problem of essential overload, we cannot reduce the amount of essential material (analogous to reducing extraneous processing in the preceding chapter), because helping students learn the essential material is the instructional goal. Thus, what we need are some techniques for managing essential processing – that is, for helping students process the essential material without experiencing essential overload. The goal of this chapter is to examine the research evidence concerning three principles of multimedia design aimed at minimizing the effects of essential overload – the segmenting principle, the pre-training principle, and the modality principle. The segmenting principle is that people learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit. The pre-training principle is that people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. The modality principle[2] is that people learn more deeply from a multimedia message when the words are spoken rather than printed.

---

[1] Throughout this chapter, I use the term *essential cognitive processing* to refer to largely the same concept as Sweller's *intrinsic cognitive load* (Sweller, Ayres, & Kalyua, 2011; see also Chapter 2)

[2] Sweller (Sweller, Ayres, & Kalyua, 2011; see also Chapter 9) considers the modality effect to be related to the split-attention effect in that both require two or more sources of information that cannot be understood in isolation and so must be mentally or physically integrated. Split-attention effects include spatial contiguity and temporal contiguity, which are examined in the preceding chapter on extraneous overload. We agree that modality effects and split-attention effects derive from the same problem; in particular, modality effects can occur when the learner must focus on two kinds of visual information presented at the same time – printed words and graphics – which may overload the learner's visual channel. We have chosen to include modality in this chapter because it corresponds to a form of essential overload (according to the taxonomy in Figure 3.3 of Chapter 3) – having too much material presented at one time to the visual system. Split-attention effects are examined in the preceding chapter because we attribute them to confusing layout (a form of extraneous overload). Thus, there appears to be no major disagreement between Sweller's analysis of the modality principle (as summarized in Chapter 9) and ours.

What Is the Theoretical Rationale for the segmenting, Pre-training, and Modality Principles

A major challenge for instructional designers is to create instructional messages that are sensitive to the characteristics of the human information processing system. In particular, the cognitive theory of multimedia learning summarized in Figure 3.2 of Chapter 3 shows that much of the cognitive processing for meaningful learning occurs within working memory. According to the cognitive theory of multimedia learning, the visual/pictorial and auditory/verbal channels in working memory are extremely limited, so that only a few items can be held or manipulated in each channel at any one time. When an instructional message – such as a narrated animation – presents a lot of unfamiliar essential material to the learner at a rapid rate, the cognitive capacity of the information processing system can become overloaded – a situation we call *essential overload*. Carrying out cognitive processing takes time, but a fast-paced presentation that requires a lot of mental model building may not allow enough time. As a result, the learner may not be able to engage in all of the cognitive processing needed for making sense of the presented material, so full understanding may not be achieved (Mayer, 2009; Mayer & Moreno, 2003).

Table 13.1 presents two overload scenarios, each involving a form of essential overload (Mayer & Moreno, 2003). In the first scenario (called *type 1 essential overload*), both channels are overloaded by essential processing demands (or intrinsic cognitive load). This overload scenario can occur when a narrated animation concerning a complex topic is presented at a fast pace. Two load-reducing methods are *segmenting* (breaking the lesson into manageable learner-controlled segments) and *pre-training* (providing the names and characteristics of key components before the lesson), both of which are explored in this chapter. The theoretical rationale for segmenting is that it slows the pace of presentation to a level that enables learners to carry out essential processing. The theoretical rationale for pre-training is that it equips learners with prior knowledge that they can use to process the subsequent narrated animation with less cognitive effort. Thus, segmenting gives them the time they need to carry out essential processing, whereas pre-training reduces the amount of essential processing that is required.

In the second overload scenario (called *type 2 essential overload*), the visual channel is overloaded by essential processing demands. This overload scenario can occur when a lesson with animation and concurrent on-screen text (or with static diagrams and printed text) is presented at a fast pace. A load-reducing method is to off-load the verbal processing from the visual channel to the auditory channel by presenting the words as narration rather than as on-screen text. This approach is also examined in Chapter 9 on the modality principle.

Table 13.1. *Load-reducing methods for two overload scenarios*

Type 1 essential overload: essential processing (in both channels) > cognitive capacity

Definition: Both channels are overloaded by essential processing demands (or intrinsic cognitive load). For example, a narrated animation on a complex topic is presented at a fast pace.

Load-reducing methods

Segmenting: Allow time between successive bite-size segments. For example, present narrated animation in learner-controlled segments rather than as a continuous unit.

Pre-training: Provide pre-training in the names and characteristics of components. For example, present narrated animation after pre-training in the names and characteristics of components rather than without pre-training.

Type 2 essential overload: essential processing in visual channel > cognitive capacity

Definition: The visual channel is overloaded by essential processing demands (or intrinsic cognitive load). For example, animation with concurrent on-screen text is presented at a fast pace.

Load-reducing method

Modality: Off-load some essential processing from the visual channel to the auditory channel. For example, present words as narration rather than as animation.

Examples of the Segmenting, Pre-training, and Modality Principles

How can we design multimedia instructional messages – such as narrated animations – so that they do not create essential overload? In other words, what can we do to a multimedia instructional message to manage the amount of essential cognitive processing that is required to take place at any one time? In this chapter, we explore three techniques for reducing essential overload – segmenting techniques, pre-training techniques, and modality techniques.

Segmenting Techniques

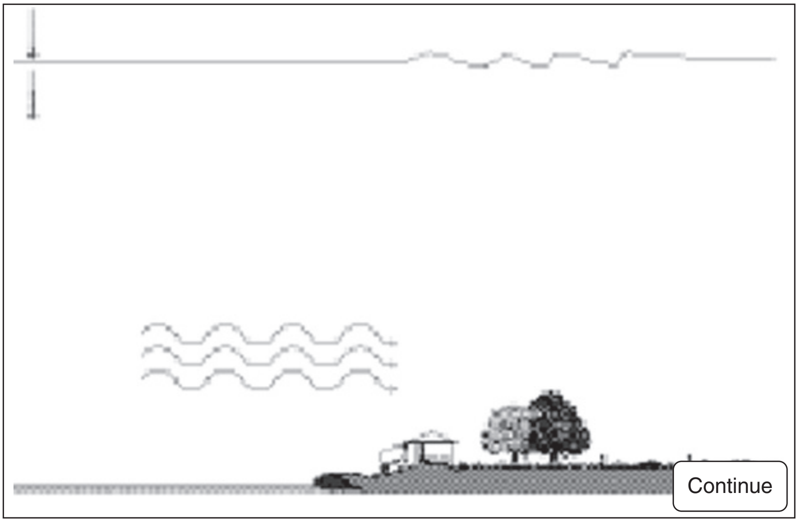
Let's begin with a narrated animation such as a 140-second narrated animation explaining the steps in the formation of lightning. Frames from the narrated animation are shown in Figure 3.1 of Chapter 3. The explanation is complex, consisting of more than a dozen steps and including more than a dozen interacting elements. Students must focus on the key words and images (such as moist cool air coming into contact with a warm surface), must note how a state change in one element causes another change (such as noting that the air rises when it becomes heated), and must relate the events to prior knowledge (such as knowing that heat causes a gas to expand and

Table 13.2. *How to break the lightning script into 16 segments*

1. Cool moist air moves over a warmer surface and becomes heated.
2. Warmed moist air near the earth's surface rises rapidly.
3. As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud.
4. The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny ice crystals.
5. Eventually, the water droplets and ice crystals become too large to be suspended by updrafts.
6. As raindrops and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts.
7. When downdrafts strike the ground, they spread out in all directions, producing the gusts of cool wind people feel just before the start of the rain.
8. Within the cloud the rising and falling air currents cause electrical charges to build.
9. The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice.
10. The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top.
11. A stepped leader of negative charges moves downward in a series of steps. It nears the ground.
12. A positively charged leader travels up from objects such as trees and buildings.
13. The two leaders generally meet about 165 feet above the ground.
14. Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright.
15. As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path.
16. The upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning.

to thereby become relatively lighter). Many students – particularly those with low levels of prior knowledge – may have difficulty keeping up with the pace of the presentation so they are not able to engage in all of the needed processing.

One solution to this essential overload problem is to allow the learner to control the pace of presentation. For example, we can break the 140-second narrated animation on lightning into 16 segments, each lasting about 10 seconds and consisting of a sentence or two. Table 13.2 shows how we can break the script of the lightning lesson into 16 segments. Further, as indicated in Figure 13.1, we can put a "Continue" button in the lower right corner of the screen that appears at the end of each animation segment. The learner can use the mouse to click on "Continue" whenever the learner is ready to go on to the next segment. When the learner has digested one segment – that is, when the learner has engaged in the cognitive processes shown in Figure 3.2 of Chapter 3 – the learner can move on to the next segment. In this way,

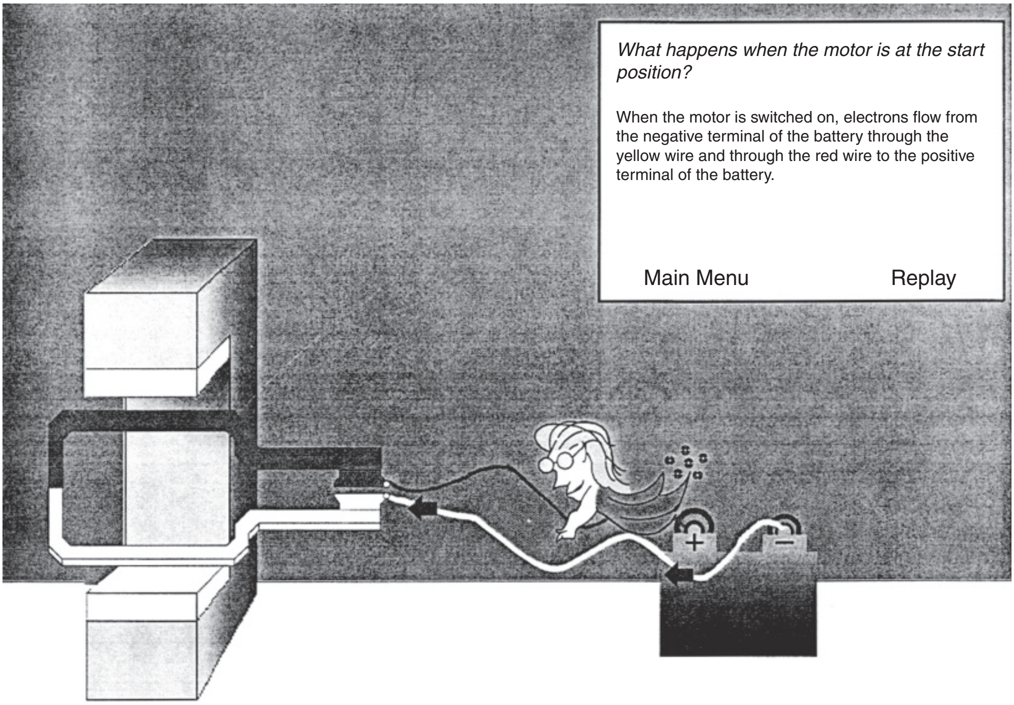


"Cool moist air moves over a warmer surface and becomes heated."

Figure 13.1. *Frame from a segmented version of the lightning lesson with a "Continue" button in the lower right corner. Adapted from Mayer and Chandler (2001).*

the learner has some modest control over the pace of presentation of the narrated animation, and thus a way of avoiding the problem of not having enough time to carry out the required cognitive processing. It is important that each verbal segment be short – involving 8–10 seconds of speech concerning one main event – so the learner can easily hold the words in working memory while viewing the corresponding animation segment.

As a second example, consider a narrated animation that explains how an electric motor works. The motor consists of many unfamiliar parts – such as a wire loop, commutator, magnet, battery, and wires – and many causal links. For an inexperienced learner, the pace of presentation may not allow for the complete cognitive processing needed to build a meaningful mental model. To alleviate this problem, we can put a list of questions in the upper right corner of the screen – for example, "What happens when the motor is in the start position?" "What happens when the motor has rotated a quarter turn?" "What happens when the motor has rotated a half turn?" "What happens when the motor has rotated three quarters of a turn?" "What happens when the motor has rotated a full turn?" The learner can click on any of the elements in the electric motor – such as the magnet or wire loop or commutator or wires or battery – and then click on any of the questions. A short segment of narrated animation or annotated animation addressing this question then appears, such as shown in Figure 13.2. In this way, the learner sees exactly the same narrated animation as in the continuous presentation but can control the pace and order of the presentation.



What happens when the motor is at the start position?

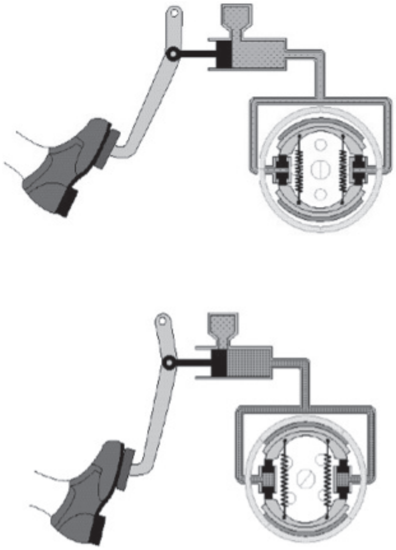
When the motor is switched on, electrons flow from the negative terminal of the battery through the yellow wire and through the red wire to the positive terminal of the battery.

Figure 13.2. *Frame from a segmented version of the electric motor lesson. Adapted from Mayer, Dow, and Mayer (2003).*

Pre-training Techniques

Another solution to the essential overload problem is to equip the learner with knowledge that will make it easier to process a narrated animation. For example, suppose we present a narrated animation explaining how a car's braking system works. The script for the lesson and some selected frames are shown in Figure 13.3. Mayer, Mathias, and Wetzell (2002) proposed a two-stage learning process in which learners first build component models for each major part in the system and then build a causal model. Building component models consists of learning the name and behavior of each component, such as learning that the piston in the master cylinder can move forward or backward, the brake fluid in the tube can be compressed or not compressed, and so on. Building a causal model consists of learning the causal chain, such as stepping on the car's brake pedal causes a piston to move forward in the master cylinder, which in turn causes brake fluid in the tube to compress, and so on.

The pace of presentation may be so fast that by the time learners are able to build component models, there is no time left to build a causal model. To overcome this overload problem, we can provide pre-training to the learners concerning the names and characteristics of each component. For example,



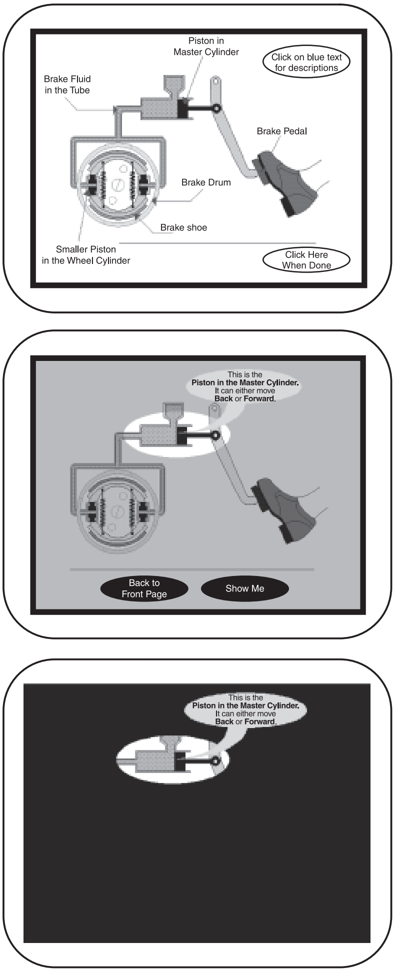
When the driver steps on the car's brake pedal, a piston moves forward inside the master cylinder. The piston forces brake fluid out of the master cylinder and through the tubes to the wheel cylinders. In the wheel cylinders, the increase in fluid pressure makes a smaller set of pistons move outward. These smaller pistons activate the brake shoes. When the brake shoes press against the drum, the wheel stops or slows down.

Figure 13.3. *Some frames and script from the brakes lesson. Adapted from Mayer, Mathias, and Wetzel (2002).*

Figure 13.4 shows frames from a pre-training episode in which learners can click on any part of a diagram of the braking system – such as the piston in the master cylinder – and then be given the name for that part and shown the states the part can be in. After the learner has clicked on each part, the learner can be shown the narrated animation explaining how a car's braking system works. However, because the learner already knows the name and characteristics of each part, the learner can engage in cognitive processes for building a causal model of the system, leading to better understanding. In this way, the pre-training provides prior knowledge that reduces the amount of processing needed to understand the narrated animation. If learners already possess prior knowledge, pre-training is not needed.

Modality Techniques

Finally, suppose you are given an animation explaining lightning formation, along with captions (one or two sentences in length) at the bottom of the screen that describe the events rendered in the animation (such as shown in the top half of Figure 13.5). In this situation, the words in the multimedia message are presented as on-screen text. This situation may overload the visual channel because the learner must look at both the animation and



When you click on "Piston in Master Cylinder"

The piston in the master cylinder is spot-lighted.

And an animation shows the piston move forward and back.

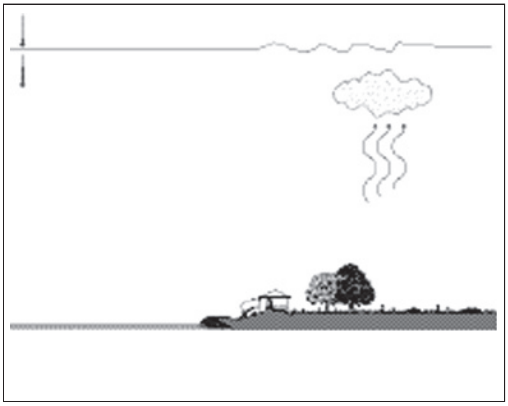
Figure 13.4. *Some frames from pre-training for the brakes lesson. Adapted from Mayer, Mathias, and Wetzel (2002).*

the on-screen text at the same time. In order to off-load some of the visual processing, we can present the words as concurrent narration (as shown in the bottom half of Figure 13.5). In this way, learners can watch the lightning animation with their eyes and listen to the verbal explanation of lightning formation with their ears.

What Do We Know about the Segmenting, Pre-training, and Modality Principles?

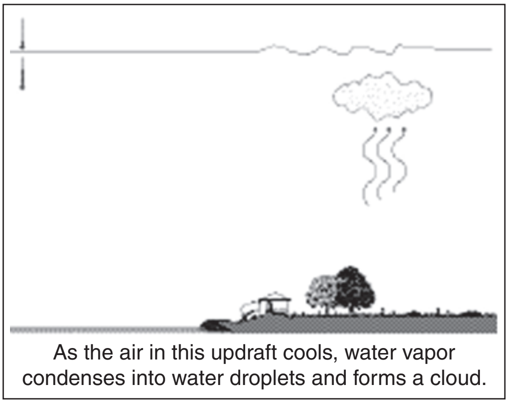
The previous edition of this handbook reported a small but consistent research base supporting the segmenting, pre-training, and modality principles. The

Words as Narration



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

Words as On-Screen Text



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

Figure 13.5. *Frames from the lightning lesson with narration (top) or onscreen text (bottom). Adapted from Mayer and Moreno (1998).*

current chapter shows that the research base has more than doubled since the previous edition, but the support for the segmenting, pre-training, and modality principles remains near the high range. The major new contributions concern the search for theory-based boundary conditions under which the principles are most likely to apply or not apply.

In this review, we consider articles published in archival journals or chapters in which (1) the task is an instructional lesson involving words and pictures; (2) the independent variable involves whether or not the presentation was segmented (i.e., continuous vs. segmented), whether or not pre-training was provided on elements in the presentation (i.e., pre-training vs. no pre-training), or whether or not the words are in spoken or printed form (i.e., spoken text vs. printed text); (3) the dependent measure is performance on a transfer test; and (4) reported statistics include the mean and standard deviation of each group. We show effect sizes separately for low-knowledge and high-knowledge learners when prior knowledge was explicitly manipulated, recognizing that strong positive effects are not expected for high-knowledge learners. We computed effect sizes for each comparison by subtracting the mean problem-solving transfer score of the control group from the mean problem-solving transfer score of the experimental group and dividing by the pooled standard deviation (Ellis, 2010). Following Cohen (1988), we consider an effect size of $d = 0.20$ to be small, $d = 0.50$ to be medium, and $d = 0.80$ to be large; and following Hattie (2009), we consider any effect size greater than $d = 0.40$ to be educationally important.

Research on the Segmenting Principle

Do students learn more deeply when an information-rich multimedia lesson is presented in learner-paced segments rather than as a continuous unit? Table 13.3 summarizes 10 comparisons between a group that received a multimedia presentation broken into segments with the pace controlled by the learner (segmented group) and a group that received the same multimedia presentation as a single continuous presentation (continuous group). The left side of the table lists the experiment that is the source of the data, the middle portion of the table lists the content of the lesson, and the right side of the table lists the effect size. Overall, in 10 of 10 comparisons, there was a positive effect size based on transfer test score, with a median effect size of $d = 0.79$.

In the first study listed in Table 13.3, Mayer and Chandler (2001) compared the learning outcomes of students who viewed a 140-second narrated animation on lightning formation as a continuous presentation (continuous group) with the learning outcomes of students who viewed the same presentation in 16 segments (segmented group). Each segment lasted about 10 seconds and contained about a sentence of narration (as shown in Table 13.2); after the narrated animation segment was complete, a "Continue" button appeared on the screen (as shown in Figure 13.1). When the learner clicked on the button, the next segment appeared. This procedure was repeated so the learner saw the continuous presentation twice or the segmented presentation twice. Line 1 of Table 13.3 shows that the segmented group performed better than the continuous group on a problem-solving transfer test, yielding a large effect size.

In a second set of studies, Mayer, Dow, and Mayer (2003) compared the learning outcomes of students who learned about electric motors from a simulation game in which they interacted with an on-screen agent named Dr. Phyz. In the continuous version, when the student clicked on the electric motor, Dr. Phyz narrated a continuous animation showing how the electric motor works. In the segmented version, a list of questions appeared corresponding to segments of the narrated animation. When the student clicked

Table 13.3. *Evidence concerning the segmenting principle*

Source	Content	Effect size
(1) Mayer and Chandler (2001, Exp. 2)	Lightning	1.13
(2) Mayer, Dow, and Mayer (2003, Exp. 2a)	Electric motor	0.82
(3) Mayer, Dow, and Mayer (2003, Exp. 2b)	Electric motor	0.98
(4) Moreno (2007, Exp. 1)	Teaching skills	0.54
(5) Moreno (2007, Exp. 2)	Teaching skills	0.77
(6) Hasler, Kersten, and Sweller (2007)	Astronomy	0.81
(7) Lusk et al. (2009, low working memory capacity)	History	0.77
(8) Boucheix and Schneider (2009)	Pulley system	0.31
(9) Stiller et al. (2009)	Human eye	0.18
(10) Hassanabadi et al. (2011)	Lightning	0.17
Median		0.79

on a question, Dr. Phyz narrated an animation concerning a segment of the presentation. When the segment was completed, the student could click on another question to see another segment of the narrated animation. As shown in lines 2 and 3 of Table 13.3, the segmented group performed much better on a transfer test than the continuous group, yielding large effect sizes in both cases.

Lines 4 and 5 summarize two experiments by Moreno (2007) in which prospective teachers received a video lesson (Exp. 1) or animated lesson (Exp. 2) on teaching skills. Either the participants had to click to continue the lesson through seven segments (segmented group), or they saw the lesson straight through (continuous group). Across both experiments the segmenting group outperformed the continuous group on measures of transfer.

In a study by Hasler, Kersten, and Sweller (2007), elementary school students watched a narrated animation on the causes of day and night. The students viewed the lesson all at once (continuous group) or in learner-paced predefined segments (segmented group). The segmented group outperformed the continuous group on low element interactivity questions ($d = 0.31$), high element interactivity questions ($d = 1.20$), and overall ($d = 0.81$, as shown in line 6).

In a study by Lusk et al. (2009), college students with low and high working memory capacity (WMC) viewed a segmented or continuous multimedia lesson on historical inquiry. Students with low WMC in the segmented group outperformed the low-WMC students in the continuous group on the application of historical inquiry methods to a new source, as shown in line 7. Segmentation did not significantly affect performance for students with high WMC, and segmentation eliminated performance differences between low- and high-WMC students.

Line 8 summarizes a study by Boucheix and Schneider (2009) in which college students learned the functioning of a pulley system from animations that were either continuous or segmented in controllable microsteps. The segmented group outperformed the continuous group on a functional mental model test (*d* = 0.31). Boucheix and Guignard (2005) reported similar results for a study involving gears, but they did not provide enough information to allow for the computation of effect size.

Line 9 summarizes a study by Stiller, Freitag, Zinnbauer, and Freitag (2009) in which college students were shown either a segmented or a continuous multimedia presentation on the structure of the human eye. The segmented group outperformed the continuous group on a transfer test when the words were printed (*d* = 0.30) but only slightly when the words were spoken (*d* = 0.06), so line 9 shows the combined effect size.

Finally, as summarized in the last line of Table 13.3, Hassanabadi, Robatjazi, and Savoji (2011) gave middle school students a multimedia lesson on lightning formation that was either segmented or continuous. The segmented group had higher transfer scores (*d* = 0.24) for narrated lessons but only slightly higher transfer scores for lessons with on-screen text (*d* = 0.09), so line 10 shows the combined effect size.

Overall, Table 13.3 shows that there is consistent evidence for the segmenting principle: people learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit. The median effect size for transfer test performance is near the large range, indicating that a modest design change that adds no new information can have a large effect on student understanding.

Can the segmenting principle be extended beyond breaking a continuous presentation into learner-paced segments? First, there is some evidence that transfer test performance can be improved when a continuous multimedia lesson is broken into segments with short pauses (e.g., of 2 or 5 seconds) between them (Khacharem, Spanjers, Soudji, Kalyuga, & Pipoll, 2013; Singh, Marcus, & Ayres, 2012). Further research is needed to disentangle the contributions of breaking a continuous presentation into bite-size segments and allowing learners to control the initiation of the next segment (also see Chapter 21 on learner control). In addition, research is needed to determine whether students learn better when they can determine the size of segments (such as by using a pause key) or when the instructor creates predetermined segments (e.g., as examined by Boucheix & Schneider, 2009; Hasler, Kersten, & Sweller, 2007).

Second, there is emerging evidence that the segmenting principle may apply to the presentation of worked examples in mathematics, with greater transfer test performance when students see problems broken into meaningful steps rather than as a single formula (Ayres, 2006; Gerjets, Scheiter, & Catrambone, 2006). However, Spanjers and colleagues obtained smaller segmenting effects on transfer scores for animated or static worked examples of probability problems (Spanjers, van Gog, & van Merriënboer, 2012; Spanjers, van Gog, Wouters, & van Merriënboer, 2012; Spanjers, Wouters, van Gog, & van Merriënboer, 2011). Further research is needed to address effective segmenting techniques for worked examples (also see Chapter 16 on worked examples).

Third, breaking complex data graphs into parts has been shown to improve transfer test performance both in the geosciences (Mautone & Mayer, 2007) and in chemistry (Lee, Plass, & Homer, 2006). Further research is needed to develop research-based design principles specific to data graphs to complement expert advice (Wong, 2010).

Some potential boundary conditions are that segmenting may have stronger effects for learners with low rather than high working memory capacity (Lusk et al., 2009) and for low-achieving rather than high-achieving learners (Ayres, 2006).

Research on the Pre-training Principle

Do students understand a multimedia lesson better if they are provided with pre-training concerning the names and characteristics of the major elements in the lesson? Table 13.4 lists 16 tests of the pre-training principle. In the first set of four studies (Pollock, Chandler, & Sweller, 2002), apprentices took a course in electrical engineering that included a two-phase multimedia lesson on conducting safety tests for electrical appliances. For some learners (pre-training group), the first phase focused on how each component worked, and the second phase focused on how all the components worked together within the electrical system. For other learners (no-pre-training group), both phases focused on how all the components worked together within the electrical system. On a subsequent problem-solving transfer test concerning how the elements worked together within the electrical system, learners with low levels of prior knowledge in the pre-training group performed better than students with low prior knowledge in the no-pre-training group, yielding large effect sizes in both cases, as shown in lines 1 and 3 of Table 13.4. In contrast, no advantage of pre-training was found for learners with high levels of prior knowledge, as shown in lines 2 and 4, indicating that high-experience learners were less likely to encounter essential overload.

In the second set of three studies (Mayer, Mathias, & Wetzell, 2002), students received a narrated animation explaining the workings of a car's braking system or a bicycle tire pump and then took problem-solving transfer tests. Before the lesson on brakes, some students (pre-training group) received pre-training in which they learned the name and possible states of each component in the brake system – for example, the piston in the master cylinder could be forward or back, the fluid in the brake tube could be compressed or not compressed, and so on. Before the tire pump lesson, some students (pre-training group) received pre-training with a clear plastic model in which they were asked to pull up and push down on the handle several times. On a subsequent test of problem-solving transfer, students in the pre-training group

Table 13.4. *Evidence concerning the pre-training principle*

Source	Content	Effect size
(1) Pollock, Chandler, and Sweller (2002, Exp. 1)	Electrical engineering (low knowledge)	1.22
(2) Pollock, Chandler, and Sweller (2002, Exp. 2)	Electrical engineering (high knowledge)	0.11
(3) Pollock, Chandler, and Sweller (2002, Exp. 3)	Electrical engineering (low knowledge)	1.15
(4) Pollock, Chandler, and Sweller (2002, Exp. 4)	Electrical engineering (high knowledge)	−0.68
(5) Mayer, Mathias, and Wetzell (2002, Exp. 1)	Brakes	0.79
(6) Mayer, Mathias, and Wetzell (2002, Exp. 2)	Brakes	0.92
(7) Mayer, Mathias, and Wetzell (2002, Exp. 3)	Tire pump	1.00
(8) Mayer, Mautone, and Prothero (2002, Exp. 2)	Geology simulation game	0.57
(9) Mayer, Mautone, and Prothero (2002, Exp. 3)	Geology simulation game	0.85
(10) Clarke, Ayres, and Sweller (2005, Exp. 1a)	Spreadsheet mathematics (low knowledge)	1.84
(11) Clarke, Ayres, and Sweller (2005, Exp. 1b)	Spreadsheet mathematics (high knowledge)	−0.38
(12) Kester, Kirschner, and van Merriënboer (2004a)	Statistics problems	−0.01
(13) Kester, Kircshner, and van Merriënboer (2004b)	Electrical circuit problems	0.06
(14) Kester, Kirshner, and van Merriënboer (2006)	Electrical circuit problems	0.72
(15) Kester et al. (2006)	Neural network problems	0.05
(16) Eitel, Scheiter, and Schüler (2013)	Pulley systems	1.37
Median		0.75

performed better than students in the no-pre-training group across all three experiments, yielding large effect sizes, as shown in lines 5–7 of Table 13.4.

Next, in a set of two studies (Mayer, Mautone, & Prothero, 2002), students learned about geology in a simulation game called the Profile Game. The goal of the game was to determine which geological feature was on a certain portion of the earth's surface, represented as a window on the computer screen. Students could use a mouse to draw lines and were shown the depth or height at each point along the line. Some students (pre-training group) were shown illustrations of the major geological features – such as a ridge or a trench – before the lesson, whereas others (no-pre-training group) were not. As can be seen in lines 8 and 9, the pre-training group performed better on a subsequent test of problem-solving transfer than did the no-pre-training group, yielding medium to large effect sizes.

In a study by Clarke, Ayres, and Sweller (2005), high school students learned about graphic representations of linear functions through a spreadsheet application. Students were divided by high and low spreadsheet skills and given instructions with either pre-training in spreadsheet skills or spreadsheet instruction presented concurrently with mathematics information. Pre-training resulted in higher performance for students with low spreadsheet skills ($d = 1.84$, as shown in line 10) but not for students with high spreadsheet skills ($d = -0.38$ as shown in line 11).

In the next series of four experiments, conducted by Kester and colleagues, students learned to solve practice problems in a computer simulation with supporting information provided either before the lesson (similar to pre-training) or during the lesson (similar to no pre-training) and then took a problem-solving transfer test. As can be seen in lines 12–15, pre-training was helpful in a study involving electrical circuits problems (Kester, Kirschner, & van Merriënboer, 2006) but not for other studies involving statistics problems (Kester, Kirschner, & van Merriënboer, 2004a), electrical circuit problems (Kester, Kirschner, & van Merriënboer, 2004a), or neural network problems (Kester, Lehnen, van Gerven, & Kirschner, 2006).

Finally, the last line of Table 13.4 summarizes a study by Eitel, Scheiter, and Schüler (2013) in which college students learned about the structure and functioning of a pulley system by reading an instructional text. When a self-paced diagram of the pulley system was presented before the lesson (as a form of pre-training), performance was improved on a comprehension test. McCrudden, Magliono, and Schraw (2011) also reported improvements on a recall test when a pre-training diagram was presented before a lesson on how kidney stones form during space travel, but this study is not included in the table because no transfer test was given.

Overall, Table 13.4 shows that most studies produced effect sizes favoring the pre-training group, with a median effect size of $d = 0.75$. These findings are consistent with the pre-training principle: people learn more deeply from a multimedia message when they know the names and characteristics of the main concepts. These findings are consistent with earlier research on advance organizers (e.g., Mayer, 1983) showing that presenting brief, supporting information before a lesson can greatly increase transfer test performance.

However, an important boundary condition suggested in Table 13.4 is that the pre-training principle may not apply to learners with high prior knowledge, perhaps because they are less likely to experience essential overload. The studies by Kester and colleagues (Kester, Kirschner, & van Merriënboer, 2004a, 2004b, 2006; Kester, Lehnen, van Gerven, & Kirschner, 2006) suggest that more work may be needed to pinpoint how best to provide supporting information when students learn by solving problems with an interactive simulation.

Research on the Modality Principle

Table 13.5 summarizes more than 60 published experimental comparisons between the transfer test performance of a group that received graphics with printed text versus a group that received graphics with spoken text. As can be seen, the modality principle has been the focus of dozens of studies and, in fact, it is the most studied of all the multimedia learning principles. This section breaks modality research into three sections – foundational research published between 1995 and 2003 (as cited in the previous edition of this handbook), subsequent research testing boundary conditions, including subsequent positive research (i.e., which produced effect sizes of $d = 0.20$ or greater), and subsequent negative research (i.e., which produced negative effect sizes or positive ones of less than $d = 0.20$).

The first 33 lines of Table 13.5 summarize foundational findings, all of which show better transfer performance for multimedia lessons consisting of graphics with spoken text rather than graphics with printed text. As Low and Sweller describe in Chapter 9, research on modality effects has a long history in cognitive psychology, but research on the modality principle in instructional contexts began in 1995 with a classic set of paper-based studies by Mousavi, Low, and Sweller (1995). Across five experiments, listed in lines 1–5, students performed much better on transfer tests after learning from paper-based lessons on how to solve geometry problems that were explained by a recorded voice rather than by text printed on the paper. Similar results were reported for paper-based lessons on electrical circuits in lines 6–8 (Tindall-Ford, Chandler, & Sweller, 1997) and graph reading on line 33 (Leahy, Chandler, & Sweller, 2003).

The remaining foundational studies in Table 13.5 involve computer-based lessons in which the graphics were presented as diagrams (Jeung, Chandler, & Sweller, 1997; Kalyuga, Chandler, & Sweller, 1999, 2000), as animation (Craig, Gholson, & Driscoll, 2002; Mayer, Dow, & Mayer, 2003; Mayer & Moreno, 1998; Moreno & Mayer, 2002, Exps. 1a and 1b; Moreno et al., 2001), or via a head-mounted display as virtual reality (Moreno & Mayer, 1999 2002; O'Neil et al., 2000). Modality effects favoring graphics with narration over graphics with printed text were found across all foundational studies, including lessons on solving mathematics problems as summarized in lines 9–11 (Jeung, Chandler, & Sweller, 1997) and in lines 24–26 (Atkinson, 2000); lightning formation in lines 12, 15, and 16 (Mayer & Moreno, 1998; Moreno & Mayer, 1999) and line 23 (Craig, Gholson, & Driscoll, 2002); an environmental science game in lines 19, 20, 21, 22, 27, 28, 29, 30, and 31 (Moreno et al., 2001; Moreno & Mayer, 2002); electrical engineering in lines 14 and 17 (Kalyuga, Chandler, & Sweller, 1999, 2000); how a car's braking system works in line 13 (Mayer & Moreno, 1998); an aircraft simulation in line 18 (O'Neil et al., 2000); and how an electric motor works in line 32 (Mayer, Dow, & Mayer, 2003). Of the 33 foundational studies, all yielded positive modality effects, with a median effect size of $d = 0.88$.

Table 13.5. *Evidence concerning the modality principle*

Source	Content	Effect size
Foundational studies		
(1) Mousavi, Low, and Sweller (1995, Exp. 1)	Geometry	0.93
(2) Mousavi, Low, and Sweller (1995, Exp. 2)	Geometry	0.88
(3) Mousavi, Low, and Sweller (1995, Exp. 3)	Geometry	0.65
(4) Mousavi, Low, and Sweller (1995, Exp. 4)	Geometry	0.68
(5) Mousavi, Low, and Sweller (1995, Exp. 5)	Geometry	0.63
(6) Tindall-Ford, Chandler, and Sweller (1997, Exp. 1)	Electrical circuits	1.68
(7) Tindall-Ford, Chandler, and Sweller (1997, Exp. 1)	Electrical circuits	1.07
(8) Tindall-Ford, Chandler, and Sweller (1997, Exp. 1)	Electrical circuits	0.23
(9) Jeung, Chandler, and Sweller (1997, Exp. 1)	Math problems	0.87
(10) Jeung, Chandler, and Sweller (1997, Exp. 2)	Math problems	0.33
(11) Jeung, Chandler, and Sweller (1997, Exp. 3)	Math problems	1.01
(12) Mayer and Moreno (1998, Exp. 1)	Lightning	1.49
(13) Mayer and Moreno (1998, Exp. 2)	Brakes	0.78
(14) Kalyuga, Chandler, and Sweller (1999, Exp. 1)	Electrical engineering	0.85
(15) Moreno and Mayer (1999b, Exp. 1)	Lightning	1.02
(16) Moreno and Mayer (1999b, Exp. 2)	Lightning	1.09
(17) Kalyuga, Chandler, and Sweller (2000, Exp. 1)	Electrical engineering (low knowledge)	0.79
(18) O'Neil et al. (2000, Exp. 1)	Aircraft simulation	1.00
(19) Moreno et al. (2001, Exp. 4a)	Environmental science game	0.60
(20) Moreno et al. (2001, Exp. 4b)	Environmental science game	1.58
(21) Moreno et al. (2001, Exp. 5a)	Environmental science game	1.41
(22) Moreno et al. (2001, Exp. 5b)	Environmental science game	1.71
(23) Craig, Gholson, and Driscoll (2002, Exp. 2)	Lightning	0.97
(24) Atkinson (2002, Exp. 1a)	Math problems	0.89
(25) Atkinson (2002, Exp. 1b)	Math problems	0.72
(26) Atkinson (2002, Exp. 2)	Math problems	0.69
(27) Moreno and Mayer (2002, Exp. 1a)	Environmental science game	0.93
(28) Moreno and Mayer (2002, Exp. 1b)	Environmental science game	0.62
(29) Moreno and Mayer (2002, Exp. 1c)	Environmental science game	2.79
(30) Moreno and Mayer (2002, Exp. 2a)	Environmental science game	0.74
(31) Moreno and Mayer (2002, Exp. 2b)	Environmental science game	2.24
(32) Mayer, Dow, and Mayer (2003, Exp. 1)	Electric motor	0.79
(33) Leahy, Chandler, and Sweller (2003, Exp. 1)	Graph reading	0.76

(*continued*)

Table 13.5. *(continued)*

Source	Content	Effect size
Studies testing boundary conditions		
(34) Tabbers, Martens, and van Merriënboer (2004)	Instructional design	−0.47
(35) Harskamp et al. (2007, Exp. 1)	Biology	0.86
(36) Harskamp et al. (2007, Exp. 2a)	Biology	1.02
(37) Owens and Sweller (2008)	Music theory	0.73
(38) Wouters, Paas, and van Merriënboer (2009)	Probability	0.52
(39) Witteman and Segers (2010)	Lightning (immediate test)	0.30
(40) Witteman and Segers (2010)	Lightning (delayed test)	−0.09
(41) Schmidt-Weigand et al. (2010a, Exp. 1a)	Lightning (slow-paced)	0.60
(42) Schmidt-Weigand et al. (2010a, Exp. 1b)	Lightning (medium-paced)	0.57
(43) Schmidt-Weigand et al. (2010a, Exp. 1c)	Lightning (fast-paced)	−0.10
(44) Schmidt-Weigand et al. (2010a, Exp. 2)	Lightning (self-paced)	0.15
(45) Schmidt-Weigand et al. (2010b, Exp. 1a)	Lightning (integrated text)	0.90
(46) Schmidt-Weigand et al. (2010b, Exp. 1b)	Lightning (separated text)	1.99
(47) Park et al. (2011)	Biology	0.54
(48) Mayrath, Nihalani, and Robinson (2011, Exp. 1)	Computer networking simulation	−0.52
(49) Mayrath, Nihalani, and Robinson (2011, Exp. 2)	Computer networking simulation	0.17
(50) Lindow et al. (2011, Exp. 2)	Lightning	−0.26
(51) Kühl et al. (2011)	Fish locomotion (dynamic visuals)	1.57
(52) Kühl et al. (2011)	Fish locomotion (static visuals)	2.69
(53) Leahy and Sweller (2011)	Temperature graphs (short segments)	0.56
(54) Leahy and Sweller (2011)	Temperature graphs (long segments)	−1.03
(55) Wong et al. (2012)	Temperature graphs (short segments)	0.66
(56) Wong et al. (2012)	Temperature graphs (long segments)	−1.01
(57) Crooks et al. (2012)	Human speech	−0.45
(58) Schüler et al. (2012)	Tornados	−1.61
(59) Schüler, Scheiter, and Gerjets (2013, Exp. 1)	Biology	0.09
(60) Schüler, Scheiter, and Gerjets (2013, Exp. 2)	Biology	0.29
(61) Cheon, Crooks, and Chung (2013)	Lightning (with pauses)	0.08
Median		0.76

In the ensuing years, research began to focus on boundary conditions for the modality principle, foreshadowed by Kalyuga, Chandler, and Sweller's (2000) finding that the modality effect was strong for learners with low prior knowledge but not for those with high prior knowledge. For example, Schmidt-Weigand, Kohnert, and Glowalla (2010a) found a modality effect when the lightning lesson was system-paced at a slow or medium pace but not when it was presented at a fast pace or self-paced (lines 41–44). Leahy and Sweller (2011) and Wong, Leahy, Marcus, and Sweller (2012) found a modality effect favoring narration when the words in a lesson on temperature graphs were presented in short segments but a reverse modality effect favoring printed words when words were presented in long segments (lines 53–56). Thus, some potentially important boundary conditions are that the modality principle might not apply when the learners are knowledgeable, the lesson is self-paced, and the verbal segments are long.

Positive modality effects were found in a biology classroom by Harskamp, Mayer, Suhre, and Jansma (2007), shown in lines 35 and 36; in a multimedia music theory lesson by Owens and Sweller (2008), showin in line 37; in a lesson on learning to solve probability problems by Wouters, Paas, and van Merriënboer (2009), shown in line 38; in a replication using the lightning lesson in German by Schmidt-Weigand, Kohnert, and Glowalla (2010b), in lines 45 and 46; in a biology lesson by Park, Moreno, Seufert, and Brunken (2011), in line 47; and in a multimedia lesson on fish locomotion by Kühl, Scheiter, Gerjests, and Edelmann (2011), in lines 51 and 52.

The modality effect was not found in a variety of situations, some of which are consistent with cognitive theory, as described by Low and Sweller in Chapter 9. For example, as shown in line 34, Tabbers, Martens, and van Merriënboer (2004) were the first to find a negative modality effect for a lesson on instructional design, which may be attributed to the use of a self-paced lesson, which can wipe out the benefits of spoken text. As another example, the strongest negative modality effect was obtained for a lesson on tornados consisting of eight static slides with captions versus with narration (Schüler, Scheiter, Rummer, & Gerjets, 2012; see line 58). A clue to the result is reflected in the fact that the negative modality effect favoring printed text was found for learners with low working memory capacity but not for those with high working memory capacity. This suggests that the transient nature of long verbal segments may be problematic when the presented words exceed what can be held in working memory for a slide. In short, the finding that the modality principle might not apply when the lesson is self-paced or the verbal segments are long is consistent with the predictions of the cognitive theory of multimedia learning.

The remaining negligible or negative effects may also be explainable in terms of boundary conditions that are consistent with cognitive theory. As summarized in lines 39 and 40, Witteman and Segers (2010) found a modest modality effect for the lightning lessons when students received an immediate test but not for a delayed test, signaling the need for more research with delayed tests. Mayrath, Nihalani, and Robinson (2011) did not find support for the modality principle in a computer networking simulation, as shown in lines 48 and 49. Lindow et al. (2011), as summarized in in line 50, and Cheon, Crooks, and Chung (2013), in line 61, did not find a modality effect for the lightning lesson, although it was modified by, for example, the addition of pauses between frames. Negative modality effects were reported by Crooks, Cheon, Ian, Ari, and Flores (2012), as summarized in line 57, with a lesson on human speech and by Schüler, Schieter, Rummer, and Gerjets (2012), line 58, with a lesson on tornados. Only small modality effects were reported by Schüler, Scheiter, and Gerjets (2013), in lines 59 and 60, for a biology lesson.

Overall, across a wide variety of learning situations, the preponderance of evidence shows that people tend to learn better from graphics and spoken text than from graphics and printed text, with a median effect size of $d = 0.76$. These findings support the modality principle: people learn more deeply from multimedia messages when the words are presented as spoken text rather than printed text.

The pattern of results in this review is consistent with an extensive meta-analysis of the modality effect conducted by Ginns (2005), yielding an overall weighted mean of $d = 0.72$ based on 43 independent comparisons. Consistent with the cognitive theory of multimedia learning, Ginns noted that the modality effect was strong for complex material but not for simple material (in which the learner may not experience cognitive load); for system-paced presentations but not for self-paced presentations (in which the effects of split attention can be overcome by spending sufficient time to read the text and view the graphic); and on transfer tests rather than retention tests (consistent with the focus of this review).

Low and Sweller's more recent review of the modality principle in Chapter 9 is consistent with this review and offers theory-based explanations for situations in which a modality effect is not observed (although Sweller and colleagues may classify the modality principle as involving extraneous rather than essential processing). Reinwein (2012) found moderate evidence for the modality principle, particularly for system-paced rather than self-paced lessons, dynamic rather than static graphics, and transfer rather than retention measures.

The growing number of failures to find a modality effect in recent years represents an important opportunity to fine-tune the cognitive theory of multimedia learning by identifying boundary conditions for when the effect is and is not found. According to the cognitive theory of multimedia learning, we would expect the modality principle to apply when the material is complex rather than simple, the presentation is system-paced rather than self-paced, the graphics are dynamic rather than static, the learners have a low level of knowledge rather than a high level, the verbal segments are short rather than long, and the words are familiar rather than unfamiliar.

The modality principle should not be taken to mean that spoken words are better than printed words in all situations. Printed words might be helpful when the verbal material contains technical terms, is in the learner's second language, or is presented in segments that are too large to be held in the learner's working memory. Instead of asking whether or not the modality effect exists, a much more promising direction is to identify theory-based boundary conditions for when it does and does not apply.

What Are the Implications of Research for Cognitive Theory?

The research results summarized in Tables 13.3, 13.4, and 13.5 provide support for the predictions of the cognitive theory of multimedia learning as summarized in Figure 3.2 of Chapter 3. When learners do not have enough capacity available to engage in active cognitive processing of the essential material, their learning outcomes suffer – as indicated by tests of problem-solving transfer. According to the cognitive theory of multimedia learning, three ways to handle an essential overload situation are to allow the learner to slow down the pace of presentation (i.e., segmenting principle), provide the learner with knowledge that reduces the need for cognitive processing of the presentation (i.e., pre-training principle), or off-load some of the visual information onto the auditory channel (i.e., modality principle). Thus, each of these principles has theoretical plausibility because it was derived from the cognitive theory of multimedia learning – particularly concerning the limited capacity for processing information in working memory. The empirical evidence in support of each of these principles provides empirical plausibility and support for the predictions of the cognitive theory of multimedia learning.

The emerging body of research on boundary conditions can be useful in fine-tuning the cognitive theory of multimedia learning. Progress can be made to the extent that boundary conditions can be explained in terms of cognitive theory. For example, we do not expect segmenting to be useful when the material is familiar and uncomplicated for the learner, because learners possess enough cognitive capacity to process the lesson. Spanjers, van Gog, & van Merriënboer (2010) propose that adding pauses to a system-paced presentation could serve the same cognitive function as segmenting, so adding a "Continue" button would not be expected to help. Similarly, we do not expect the pre-training principle to apply to learners with high prior knowledge because they already possess the information presented in pre-training. Finally, we do not expect the modality principle to apply when the lesson is self-paced (so learners can compensate for overloading situations), the verbal material is lengthy (so the transitory nature of spoken text is problematic), or when learners have a high level of prior knowledge (so they can process the lesson under a variety of conditions).

What Are the Implications of Research for Instructional Design?

The research reviewed in this chapter shows that instructional designers should be sensitive to working memory constraints when presenting a complex multimedia lesson. For example, if a concise narrated animation contains a lot of interacting concepts and is presented at a fast pace, the demand for cognitive processing can exceed the learner's cognitive capacity. Even if extraneous material has been eliminated from the presentation, the remaining essential material may be presented at a rate that exceeds the learner's capacity. The segmenting, pre-training, and modality principles are particularly relevant to the design of narrated animations, narrated videos, or narrated slideshows that contain a lot of interacting concepts presented at a fast pace. According to the segmenting principle, it would be useful to break a narrated animation into meaningful segments and to allow the learner to control the onset of each segment, such as by clicking on a "Continue" button. According to the pre-training principle, it would be useful to sequence the instruction to begin with descriptions of the key concepts or elements before describing how they interact. According to the modality principle, it would be useful to use narrated animation rather than animation with on-screen text. Furthermore, the designer should take learner characteristics into account and be aware that well-designed multimedia instruction may be most effective for low-experience learners.

What Are the Limitations of Current Research and What Are Some Productive Directions for Future Research?

The principles described in this chapter are subject to limitations inherent in the nature of the task and in the dependent measures. Concerning the nature of the task, most of the research studies involved short narrated animations presented in a controlled laboratory environment with an immediate test. Research is needed in which the principles are tested within more ecologically valid environments, such as with students in their classrooms, as was done by Harskamp et al. (2007). Concerning the dependent measures, we have focused on measures of transfer because we are most interested in improving learners' understanding. However, a central assumption underlying the principles described in this chapter is that they work because they effectively reduce cognitive load. Thus, it would be useful to include direct measures of cognitive load in future research (Brunken, Plass, & Leutner, 2003; Brunken, Seufert, & Paas, 2010; DeLeeuw & Mayer, 2008).

Further research work is also needed to better understand the conditions under which each of the principles is most effective. Concerning the segmenting principle, some of the studies focused solely on allowing the learner to control the pace of presentation, whereas others focused on allowing the learner to control both the pace and order of presentation. Research is needed to determine the relative effects of learner control of presentation pace and learner control of presentation order, and whether such effects depend on the characteristics of the learner and on the characteristics of the learning task. For example, inexperienced learners may lack the metacognitive skills to make effective decisions about the order of presentation, whereas experienced learners may be able to make such decisions effectively. The role of the learner's prior knowledge is examined in detail by Kalyuga in Chapter 24.

Also concerning segmenting, research is needed to determine the most effective size of a segment and whether optimal segment size depends on the characteristics of the learner and the learning task. In some of the studies reported in this chapter, the segments were fairly short – approximately 10 seconds of animation along with a few sentences of narration – and the segments described meaningful steps in a process. Having segments that are too small may distract and irritate some learners, whereas having segments that are too long may result in cognitive overload.

Concerning pre-training, research is needed to extend the principle beyond cause-and-effect systems. In the studies reported in this chapter, the learning goal was to understand how some mechanical or physical system works. In such situations, it was useful to know the names and behaviors of each component before learning about the causal model. Further research is needed to determine whether similar benefits of pre-training occur for different kinds of lessons, such as an explanation of how to solve a mathematics problem or an analysis of a historical controversy.

Concerning modality, there may be situations in which on-screen text would be helpful, such as for lessons with complex technical terms or long segments of unfamiliar text or for learners who are non-native speakers or who have hearing disabilities. Further research is needed to determine the conditions for the modality principle and how they relate to cognitive theory.

Glossary

Cognitive capacity: The total amount of processing that can be supported by a learner's working memory at any one time.

Concise narrated animation: A narrated animation that contains *essential material* – needed for understanding the lesson – but does not contain *extraneous material* – material not needed for understanding the lesson.

Essential material: Words and pictures needed to achieve an instructional objective, such as understanding how a mechanical system works.

Essential overload: Overload that occurs when the amount of essential cognitive processing required to understand the multimedia instructional message exceeds the learner's cognitive capacity.

Essential processing: Cognitive processing – such as selecting relevant words and images and organizing them as presented – required to represent the essential material; similar to Sweller's (1999) intrinsic cognitive load.

Modality principle: People learn more deeply from multimedia presentations when words are spoken rather than printed.

Pre-training principle: People learn more deeply from a multimedia message when they know the names and characteristics of the main concepts.

Segmenting principle: People learn more deeply when a multimedia message is presented in learner-paced segments rather than as a continuous unit.

Acknowledgment

This chapter is based on chapter 11 in the first edition of the *Cambridge Handbook of Multimedia Learning.* Preparation of the chapter was supported by a grant from the Office of Naval Research. We appreciate the helpful comments of Jeroen van Merriënboer and John Sweller.

References

Ayres, P. (2006). Impact of reducing intrinsic cognitive load on learning in a mathematical domain. *Applied Cognitive Psychology*, *20*(3), 287–298.

Boucheix, J., & Guignard, H. (2005). What animated illustrations conditions can improve technical document comprehension in young students? Format, signaling and control of the presentation. *European Journal of Psychology of Education*, *20*, 369–388.

Boucheix, J., & Schneider, E. (2009). Static and animated presentations in learning dynamic mechanical systems. *Learning and Instruction*, *19*(2), 112–127.

Brunken, R., Plass, J. L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, *38*, 53–62.

Brunken, R., Seifert, T., & Paas, F. (2010). Measuring cognitive load. In J. L. Plass, R. Moreno, & R. Brunken (Eds.), *Cognitive load theory* (pp. 181–202). New York: Cambridge University Press.

Cheon, J., Crooks, S., & Chung, S. (2013). Does segmenting principle counteract modality principle in instructional animation? *British Journal of Educational Technology*. Online first publication.

Clarke, T., Ayres, P., & Sweller, J. (2005). The impact of sequencing and prior knowledge on learning mathematics through spreadsheet applications. *Educational Technology Research and Development*, *53*(3), 15–24.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2d ed.). Hillsdale, NJ: Lawrence Erlbaum.

Craig, S. D., Gholson, B., & Driscoll, D. M. (2002). Animated pedagogical agents in multimedia educational environments: Effects of agent properties, picture features, and redundancy. *Journal of Educational Psychology*, *94*, 428–434.

Crooks, S. M., Cheon, J., Inan, F., Ari, F., & Flores, R. (2012). Modality and cueing in multimedia learning: Examining cognitive and perceptual explanations for the modality effect. *Computers in Human Behavior*, *28*, 1063–1071.

DeLeeuw, K. E., & Mayer, R. E. (2008). A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. *Journal of Educational Psychology*, *100*, 223–234.

Eitel, A., Scheiter, K., & Schüler, A. (2013). How inspecting a picture affects processing of text in multimedia learning. *Applied Cognitive Psychology*, *27*, 451–461.

Ellis, P. D. (2010). *The essential guide to effect sizes*. New York: Cambridge University Press.

Gerjets, P., Scheiter, K., & Catrambone, R. (2006). Can learning from molar and modular worked examples be enhanced by providing instructional explanations and prompting self-explanations? *Learning and Instruction*, *16*(2), 104–121.

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction*, *15*, 313–332.

Harskamp, E. G., Mayer, R. E., & Suhre, C. (2007). Does the modality principle for multimedia learning apply to science classrooms? *Learning and Instruction*, *17*, 465–477.

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load, and instructional animation. *Applied Cognitive Psychology*, *21*, 713–729.

Hassanabadi, H., Robatjazi, E. S., & Savoji, A. P. (2011). Cognitive consequences of segmentation and modality methods in learning from instructional animations. *Procedia – Social and Behavioral Sciences*, *30*, 1481–1487.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* New York: Routledge.

Jeung, H., Chandler, P., & Sweller, J. (1997). The role of visual indicators in dual sensory mode instruction. *Educational Psychology*, *17*, 329–343.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology*, *13*, 351–371.

Kalyuga, S., Chandler, P., & Sweller, J. (2000). Incorporating learner experience into the design of multimedia instruction. *Journal of Educational Psychology*, *92*, 126–136.

Kester, L., Kirschner, P. A., van Merriënboer, J. J. G. (2004a). Timing of information presentation in learning statistics. *Instructional Science*, *32*, 233–252.

Kester, L., Kirschner, P. A., van Merriënboer, J. J. G. (2004b). Information presentation and troubleshooting in electrical circuits. *International Journal of Science Education*, *26*, 239–256.

Kester, L., Kirschner, P. A., van Merriënboer, J. J. G. (2006). Just-in-time information presentation: Improving learning a troubleshooting skill. *Contemporary Educational Psychology*, *31*, 167–185.

Kester, L., Lehnen, C., van Gerven, P. W. M., & Kirschner, P. A. (2006). Just-in-time, schematic supporting information presentation during cognitive skill acquisition. *Computers in Human Behavior*, *22*, 93–112.

Khacharem, A., Spanjers, I. A. E., Zoudji, B., Kalyuga, S., & Ripoll, H. (2013). Using segmentation to support the learning from animated soccer scenes: An effect of prior knowledge. *Psychology of Sport and Exercise*, *14*, 154–160.

Kühl, T., Scheiter, K., Gerjets, P., & Edelmann, J. (2011). The influence of text modality on learning with static and dynamic visualizations. *Computers in Human Behavior*, *27*(1), 29–35.

Leahy, W., Chandler, P., & Sweller, J. (2003). When auditory presentations should and should not be a component of multimedia instruction. *Applied Cognitive Psychology*, *17*, 401–418.

Leahy, W., & Sweller, J. (2011). Cognitive load theory, modality of presentation and the transient information effect. *Applied Cognitive Psychology*, *25*(6), 943–951.

Lee, H., Plass, J. L., & Homer, B. D. (2006). Optimizing cognitive load for learning from computer-based science simulations. *Journal of Educational Psychology*, *98*, 902–913.

Lindow, S., Fuchs, H. M., Fürstenberg, A., Kleber, J., Schweppe, J., & Rummer, R. (2011). On the robustness of the modality effect: Attempting to replicate a basic finding. *Zeitschrift für Pädagogische Psychologie*, *25*(4), 231–243.

Lusk, D. L., Evans, A. D., Jeffrey, T. R., Palmer, K. R., Wikstrom, C. S., & Doolittle, P. E. (2009). Multimedia learning and individual differences: Mediating the effects of working memory capacity with segmentation. *British Journal of Educational Technology*, *40*(4), 636–651.

Mautone, P. D., & Mayer, R. E. (2007). Cognitive aids for guiding graph comprehension. *Journal of Educational Psychology*, *99*, 640–652.

Mayer, R. E. (1983). Can you repeat that? Qualitative effects of repetition and advance organizers on learning from science prose. *Journal of Educational Psychology*, *75*, 40–49.

Mayer, R. E. (2009). *Multimedia learning* (2d ed.). New York: Cambridge University Press.

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*, 390–397.

Mayer, R. E., Dow, G., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology*, *95*, 806–813.

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*, 147–154.

Mayer, R. E., Mautone, P., & Prothero, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology*, *94*, 171–185.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: Evidence for dual processing systems in working memory. *Journal of Educational Psychology*, *90*, 312–320.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, *38*, 43–52.

Mayrath, M. C., Nihalani, P. K., & Robinson, D. H. (2011). Varying tutorial modality and interface restriction to maximize transfer in a complex simulation environment. *Journal of Educational Psychology*, *103*(2), 257–268.

McCrudden, M. T., Magliano, J. P., & Schraw, G. (2011). The effect of diagrams on online reading processes and memory. *Discourse Processes*, *48*, 69–92.

Moreno, R. (2007). Optimising learning from animations by minimising cognitive load: Cognitive and affective consequences of signaling and segmentation methods. *Applied Cognitive Psychology*, *21*, 765–781.

Moreno, R., & Mayer, R. E. (1999) Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology*, *91*, 358–368.

Moreno, R., & Mayer, R. E. (2002). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psychology*, *94*, 598–610.

Moreno, R., Mayer, R. E., Spires, H., & Lester, J. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction*, *19*, 177–213.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology*, *87*, 319–334.

O'Neil, H. F., Mayer, R. E., Herl, H. E., Niemi, C., Olin, K., & Thurman, R. A. (2000). Instructional strategies for virtual aviation training environments. In H. F. O'Neil & D. H. Andrews (Eds.), *Aircrew training and assessment* (pp. 105–130). Mahwah, NJ: Lawrence Erlbaum.

Owens, P., & Sweller, J. (2008). Cognitive load theory and music instruction. *Educational Psychology*, *28*(1), 29–45.

Park, B., Moreno, R., Seufert, T., & Brünken, R. (2011). Does cognitive load moderate the seductive details effect? A multimedia study. *Computers in Human Behavior*, *27*(1), 5–10.

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. *Learning and Instruction*, *12*, 61–86.

Reinwein, J. (2012). Does the modality effect exist? And if so, which modality effect? *Journal of Psycholinguistic Research*, *41*, 1–32.

Schmidt-Weigand, F., Kohnert, A., & Glowalla, U. (2010a). A closer look at split visual attention in system and self-paced instruction in multimedia learning. *Learning and Instruction*, *20*, 100–110.

Schmidt-Weigand, F., Kohnert, A., & Glowalla, U. (2010b). Explaining the modality and contiguity effects: New insights from investigating students' viewing behaviour. *Applied Cognitive Psychology*, *24*, 226–237.

Schüler, A., Scheiter, K., & Gerjects, P. (2013). Is spoken text always better? Investigating the modality and redundancy effect with longer text presentation. *Computers in Human Behavior*, *29*, 1590–1601.

Schüler, A, Scheiter, K., Rummer, R., & Gerjets, P. (2012). Explaining the modality effect in multimedia learning: Is it due to a lack of temporal contiguity with written text and pictures? *Learning and Instruction*, *22*, 92–102.

Singh, A., Marcus, N., & Ayres, P. (2012). The transient information effect: Investigating the impact of segmentation on spoken and written text. *Applied Cognitive Psychology*, *26*, 848–853.

Spanjers, I. A. E., van Gog, T., & van Merriënboer, J. J. G. (2010). A theoretical analysis of how segmentation of dynamic visualizations optimizes students' learning. *Educational Psychology Review*, *22*, 411–423.

Spanjers, I. A. E., van Gog, T., & van Merriënboer, J. J. G. (2012). Segmentation of worked examples: Effects on cognitive load and learning. *Applied Cognitive Psychology*, *26*, 352–358.

Spanjers, I. A. E., van Gog, T., Wouters, P., & van Merriënboer, J. J. G. (2012). Explaining the segmentation effect in learning from animations: The role of pausing and temporal cueing. *Computers & Education*, *59*(2), 274–280.

Spanjers, I. A. E., Wouters, P., van Gog, T., & van Merriënboer, J. J. G. (2011). An expertise reversal effect of segmentation in learning from animated worked-out examples. *Computers in Human Behavior*, *27*, 46–52.

Stiller, K. D., Freitag, A., Zinnbauer, P., & Freitag, C. (2009). How pacing of multimedia instructions can influence modality effects: A case of superiority of visual texts. *Australasian Journal of Educational Technology*, *25*(2), 184–203.

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

Tabbers, H. K., Martens, R. L., & can Merriënboer, J. J. G. (2004). Multimedia instructions and cognitive load theory: Effects of modality and cueing. *British Journal of Educational Psychology*, *74*, 71–81.

Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When two sensory modes are better than one. *Journal of Experimental Psychology: Applied*, *3*, 257–287.

Witteman, M. J., & Segers, E. (2010). The modality effect tested in children in a user-paced multimedia environment. *Journal of Computer Assisted Learning*, *26*(2), 132–142.

Wong, A., Leahy, W., Marcus, N., & Sweller, J. (2012). Cognitive load theory, the transient information effect and e-learning. *Learning and Instruction*, *22*, 449–457.

Wong, D. M. (2010). *The Wall Street Journal guide to information graphics*. New York: Norton.

Wouters, P., Paas, F., & van Merriënboer, J. J. G. (2009). Observational learning from animated models: Effects of modality and reflection on transfer. *Contemporary Educational Psychology*, *34*(1), 1–8.