12 Principles for Reducing Extraneous Processing in Multimedia Learning: Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles

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Abstract

Extraneous overload occurs when essential cognitive processing (required to understand the essential material in a multimedia message) and extraneous cognitive processing (required to process extraneous material or to overcome confusing layout in a multimedia message) exceed the learner's cognitive capacity. Five multimedia design methods intended to minimize extraneous overload are based on the coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. The coherence principle is that people learn more deeply from a multimedia message when extraneous material is excluded rather than included. This principle was supported in 23 out of 23 experimental tests, yielding a median effect size of 0.86. The signaling principle is that people learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material. This principle was supported in 24 out of 28 experimental tests, yielding a median effect size of 0.41. The redundancy principle is that people learn more deeply from graphics and narration than from graphics, narration, and on-screen text. This principle was supported in 16 out of 16 experimental tests, yielding a median effect size of 0.86. The spatial contiguity principle is that people learn more deeply from a multimedia message when corresponding words and pictures are presented near rather than far from each other on the page or screen. This principle was supported in 22 out of 22 experimental tests, yielding a median effect size of 1.10. The temporal contiguity principle is that people learn more deeply from a multimedia message when

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corresponding animation and narration are presented simultaneously rather than successively. This principle was supported in 9 out of 9 experimental tests, yielding a median effect size of 1.22.

What Are the Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles?

Consider a multimedia learning situation in which so much extraneous material is included or the layout is so confusing that the learner is not able to adequately process the essential material. This situation creates a cognitive processing challenge that can be called *extraneous overload* (as described in Chapter 3). Extraneous overload occurs when essential cognitive processing (required to understand the essential material in a multimedia message) and extraneous cognitive processing (required to process extraneous material or to overcome confusing layout in a multimedia message) exceed the learner's cognitive capacity. *Essential material* refers to words and pictures needed to achieve the instructional objective, such as understanding how a mechanical system works, and requires processing similar to Sweller's (1999; Sweller, Ayres, & Kalyuga, 2011; also see Chapter 2) *intrinsic cognitive load*. *Extraneous material* refers to words and pictures that are not relevant to achieving the instructional objective, such as interesting stories or pictures, and requires processing similar to Sweller's (1999; Sweller, Ayres, & Kalyuga, 2011; also see Chapter 2) *extraneous cognitive load*. *Cognitive capacity* refers to the total amount of processing that can be supported by the learner's working memory at any one time.

The purpose of this chapter is to explore research evidence for five theory-based instructional design techniques intended to reduce extraneous overload: the coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. The *coherence principle* is that people learn more deeply from a multimedia message when extraneous material is excluded rather than included. The *signaling principle* is that people learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material. The *redundancy principle* is that people learn more deeply from graphics and narration than from graphics, narration, and on-screen text. The *spatial contiguity principle* is that people learn more deeply from a multimedia message when corresponding words and pictures are presented near rather than far from each other on the page or screen. The *temporal contiguity principle* is that people learn more deeply from a multimedia message when corresponding animation and narration are presented simultaneously rather than successively.

What Is the Theoretical Rationale for the Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles?

Principles for reducing extraneous cognitive load are based on the cognitive theory of multimedia learning summarized in Figure 3.2 of Chapter 3. In particular, according to the cognitive theory of multimedia learning, much of the cognitive processing required for building a meaningful learning outcome – such as selecting, organizing, and integrating – occurs in working memory. Three important features of working memory are (1) dual channels – that is, there are separate channels for visual and verbal processing, (2) limited capacity – that is, there are severe limits on the amount of processing that can occur in each channel at any one time, and (3) active processing – that is, meaningful learning requires engaging in cognitive processing such as selecting, organizing, and integrating (as described in Chapter 3). A major challenge for instructional designers is to create instructional messages that are sensitive to the characteristics of the human information processing system, so that the amount of processing required in each channel of working memory does not exceed the learner's cognitive capacity.

When an instructional message contains a lot of essential material and a lot of extraneous material, the cognitive capacity of the information processing system is easily overloaded – a situation we call *extraneous overload*. Carrying out cognitive processing takes time and effort – both of which are limited. If the learner is required to engage in extraneous processing – that is, processing of extraneous material – the learner may not be able to engage in essential processing – that is, the cognitive processing needed to make sense of the essential material. As a result, the learner might not achieve full understanding of the material (Mayer, 2009; Mayer & Moreno, 2003; see also Chapter 3).

Table 12.1 presents three overload scenarios, each involving a form of extraneous overload (Mayer & Moreno, 2003), in which essential processing demands (or intrinsic cognitive load) and extraneous processing demands (or extraneous cognitive load) exceed the learner's cognitive capacity. In the first scenario (*type 1 extraneous overload*), one or both channels are overloaded by the need to process essential material and the need to process extraneous material. This overload scenario can occur when a multimedia instructional message contains too much detail, embellishment, or gratuitous information or when the layout of material is confusing. Two load-reducing methods for combating this scenario are based on the *coherence principle* and the *signaling principle*, both of which are explored in this chapter. The theoretical rationale for employing the coherence principle is that it weeds out irrelevant material, thereby enabling the learner to use more available cognitive capacity for essential processing. The theoretical rationale for employing the *signaling principle*

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Table 12.1. *Load-reducing methods for three overload scenarios*

Type 1 extraneous overload: essential processing + extraneous processing (caused by extraneous material) > cognitive capacity
Definition: One or both channels are overloaded by essential processing and extraneous processing (attributable to extraneous material). For example, a multimedia lesson contains extraneous words and/or pictures.
Load-reducing methods
Coherence: Eliminate extraneous material to reduce processing of extraneous material. For example, exclude interesting but irrelevant statements or graphics.
Signaling: Provide cues for how to process the lesson to reduce processing of extraneous material. For example, add signals that show the learner what to attend to and how to organize it.
Redundancy: Avoid presenting identical streams of printed and spoken words concurrently with corresponding animation. For example, present words as narration rather than as narration and on-screen text.
Type 2 extraneous overload: essential processing + extraneous processing (caused by confusing layout) > cognitive capacity
Definition: One or both channels are overloaded by essential processing and extraneous processing (attributable to a confusing layout). For example, a multimedia lesson presents essential words and/or pictures in a confusing layout.
Load-reducing method
Spatial contiguity: Place printed words near corresponding parts of graphics to reduce the need for visual scanning. For example, put printed words near rather than far from corresponding parts of an illustration (on paper) or animation (on a screen).
Type 3 extraneous overload: essential processing + representational holding (caused by confusing layout) > cognitive capacity
Definition: One or both channels are overloaded by essential processing and representational holding. For example, an animation is presented before or after a corresponding narration.
Load-reducing method
Temporal contiguity: Present corresponding narration and animation at the same time to minimize the need to hold representations in memory. For example, present corresponding narration and animation simultaneously rather than successively.

is that it directs the learner's attention toward essential material, thereby enabling the learner to ignore extraneous material and use more available cognitive capacity to process essential material. Thus, coherence techniques eliminate extraneous material – and thus extraneous processing – whereas signaling techniques guide the learner's attention toward essential material – thus eliminating the need for processing of extraneous material.

Alternatively, this overload scenario can occur with animation (or illustrations) and narration when redundant on-screen text is added. A load-reducing technique for addressing this situation based on the *redundancy principle* is to eliminate the redundant on-screen text. The theoretical rationale for

employing the redundancy principle is that it reduces extraneous processing, such as trying to reconcile the auditory and printed stream of words, and it eliminates the problem of having to process both animation (or illustration) and printed words in the visual channel (as discussed in relation to the modality principle in Chapter 13). Thus, redundant printed text can be seen as a special case of extraneous material. Redundancy techniques eliminate this extraneous material altogether.

In the second overload scenario (*type 2 extraneous overload*), one or both channels are overloaded by essential processing (attributed to understanding the essential material) and extraneous processing (attributed to dealing with a poorly designed layout). This overload scenario can occur with text and graphics when corresponding printed text and graphics are far from each other on the page or screen, causing the learner to visually search for the connection between them. A load-reducing technique is based on the *spatial contiguity principle*, which calls for placing printed words near rather than far from corresponding parts of an illustration or animation. The theoretical rationale for the spatial contiguity principle is that it reduces the effort required to scan back and forth between the text and the graphic. Eye movement studies by Hegarty, Carpenter, and Just (1996) have shown that students tend to read a portion of text and then look for the corresponding portion of the graphic, then read the next portion of text and look for the corresponding portion of the graphic, and so on. Spatial contiguity techniques can reduce the effort involved in visually scanning the screen or page – a form of extraneous processing. Thus, spatial contiguity techniques provide cues that direct the learner's attention toward better integration between corresponding text and graphics.

In the third overload scenario (*type 3 extraneous overload*), both channels are overloaded by essential processing and representational holding (i.e., a form of extraneous processing caused by maintaining a mental representation in working memory for a long period of time). This overload scenario can occur when an animation explaining a topic is presented before or after a corresponding narration explaining the same topic. A load-reducing method based on the temporal contiguity principle is to present corresponding narration and graphics simultaneously. The theoretical rationale for the temporal contiguity principle is that it ensures that corresponding words and pictures are in working memory at the same time, thereby eliminating the need to hold a representation in working memory for an extended period of time.

Examples of the Coherence, Signaling, Redundancy, Spatial Continuity, and Temporal Contiguity Principles

How can we modify multimedia instructional messages so that they do not create extraneous overload? In other words, what can we do to a

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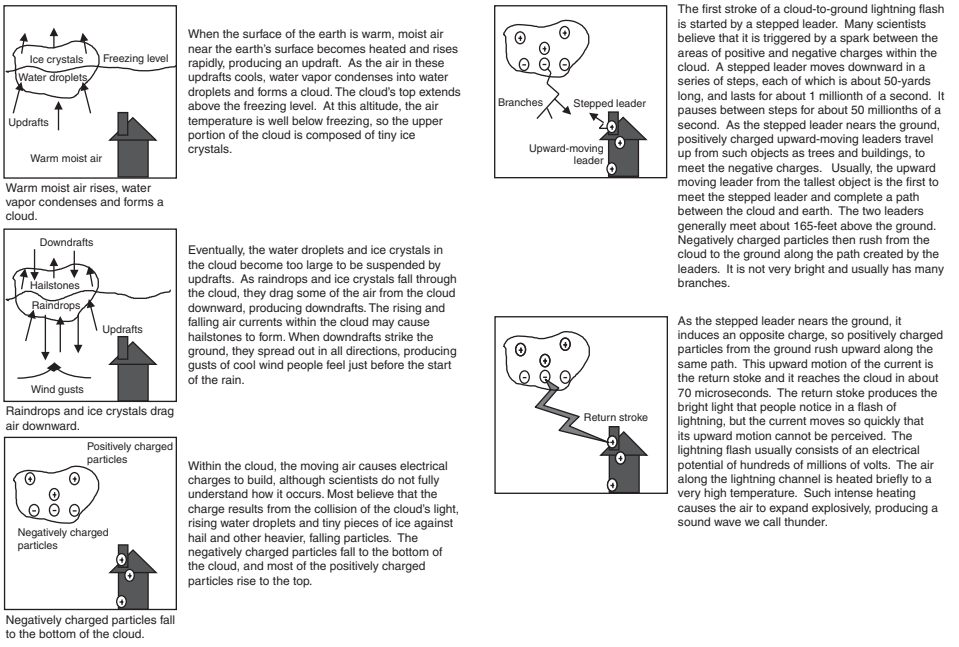

Figure 12.1. *Book-based integrated presentation on lightning.*

multimedia instructional message to reduce the amount of extraneous cognitive processing that is required of learners? In this chapter, we explore five techniques for reducing extraneous overload – coherence, signaling, redundancy, spatial contiguity, and temporal contiguity. In each case, the cognitive theory of multimedia learning predicts that reducing extraneous processing will increase the quality of the learning outcome as manifested in improved performance on problem-solving transfer tests.

Coherence Techniques

Sometimes a multimedia message contains words and/or pictures that are not relevant to the instructional goal. For example, consider a book-based lesson that explains the steps in lightning formation using printed words and illustrations, including the words shown in Figure 12.1. We could spice the lesson up by inserting additional sentences in each paragraph describing interesting stories about lightning, such as an incident in which a high school student was struck by lightning while playing football, as shown in Table 12.2. Alternatively, consider a computer-based lesson that explains lightning formation using narration and animation, as exemplified in Figure 3.1 of Chapter 3. To spice up the lesson we could add short video clips of lightning storms along with interesting facts about lightning (sometimes called *seductive details*), or we could include background music and environmental sounds.

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Table 12.2. *Portion of added text from embellished lessons on lightning*

Inserted in the first paragraph
When flying through updrafts, an airplane ride can become bumpy. Metal airplanes conduct lightning very well, but they sustain little damage because the bolt, meeting no resistance, passes right through.
Inserted in the second paragraph
When lightning strikes the ground, fulgurites may form, as the heat from the lightning fuses sand into the shape of the electricity's path.
Inserted in the third paragraph
In trying to understand these processes, scientists sometimes create lightning by launching tiny rockets into overhead clouds.
Inserted in the fourth paragraph
Golfers are prime targets of lightning strikes because they tend to stand in open grassy fields or huddle under trees.
Inserted in the fifth paragraph
Approximately 10,000 Americans are injured by lightning every year. Eyewitnesses in Burtonsville, Maryland, watched as a bolt of lightning tore a hole in the helmet of a high school football player during practice. The bolt burned his jersey and blew his shoes off. More than a year later, the young man still won't talk about his near-death experience.

A straightforward solution to the extraneous overload problem here is to eliminate words, pictures, and sounds that are not relevant to the instructional goal. For example, we could eliminate the extraneous printed words and illustrations from the book-based lesson on lightning (i.e., by not using the words in Table 12.2), or we could eliminate the extraneous video or music from the computer-based lesson.

Signaling Techniques

Another solution to the problem of having too much extraneous material in a multimedia lesson is to insert cues that direct the learner's attention toward the essential material. For example, suppose we present a narrated animation explaining how an airplane achieves lift, using the script shown in Table 12.3 (without the underlined sentences and without emphasizing the bolded words). This script contains some material that is not essential to understanding the process of lift, so we can direct the learner's attention by using signals such as an outlining sentence that lists the main steps (indicated by the underlined sentences inserted at the end of the first paragraph in Table 12.3), headings for each step (as shown in the underlined phrases before the second, third, and fifth paragraphs), and spoken emphasis on key words (indicated by the words in bold font). As you can see, the signals do not add or remove any new information but rather highlight the essential material in the lesson.

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Table 12.3. *Portion of script for lessons on airplane lift*

What is needed to cause an aircraft, which is heavier than air, to climb into the air and stay there? An aerodynamic principle formulated by Daniel Bernouille in 1738 helps explain it. Bernouille's principle explains how upward forces, called lift, act upon the plane when it moves through the air. To understand how lift works, you need to focus on differences between the top and bottom of the airplane's wing: first, how the top of the wing is **shaped** differently than the bottom; second, how quickly **air flows** across the top surface, compared with across the bottom surface; and third, how the **air pressure** on the wing compares with that on the bottom of the wing.

Wing shape: Curved upper surface is longer. A cross section of a bird's wing, a boomerang, and a Stealth bomber all share a shape similar to that of an airplane wing. The upper surface of the wing is curved more than the bottom surface. The surface on the **top** of the wing is **longer** than on the **bottom**. This is called an airfoil.

Air flow: Air moves faster across top of wing. In order to achieve lift, air must flow over the wing. The wingspan of a 747 is more than 200 feet; that's taller than a 15-story building. When the airplane moves forward, its wings cut through the air. As the air moves across the wing, it will push against it in all directions, perpendicular to the surface of the wing.

When an airplane is in flight, air hitting the front of the wing separates. Some air flows over the wing and some flows under the wing. The air meets up again at the back of the wing. The air flowing over the top of the wing has a longer distance to travel in the same amount of time. Air traveling over the curved **top** of the wing **flows faster** than air that flows under the **bottom** of the wing.

Air pressure: Pressure on the top is less. When air moves faster, its pressure decreases. You have probably noticed that when you turn on the water in the shower, the curtain moves in. The running water makes the air in the shower move faster and since it exerts less pressure against the curtain than the still air outside the curtain does, the curtain is pushed in. A similar principle is at work on airplane wings.

Since the air over the top of the wing is moving faster, it gets more spread out and therefore pressure on the top part of the wing decreases. The **top** surface of the wing now has **less pressure** exerted against it than the **bottom** surface of the wing. The downward force of the faster-moving air on the top of the wing is not as great as the upward force of the slower-moving air under the wing and, as a result, there is a net upward force on the wing – a lift.

Note: Signaling consists of added outline and headings indicated by underlining, and spoken emphasis is indicated by bold-face type.

Redundancy Techniques

Suppose you are viewing a narrated animation on lightning formation as exemplified by the top half of Figure 12.2. We refer to this as a *nonredundant multimedia presentation* because the words are presented in spoken form only. It might be tempting to add concurrent on-screen text that mirrors the narration, in an attempt to accommodate various learning styles, as exemplified by the lower half of Figure 12.2. In this case, the narrator speaks

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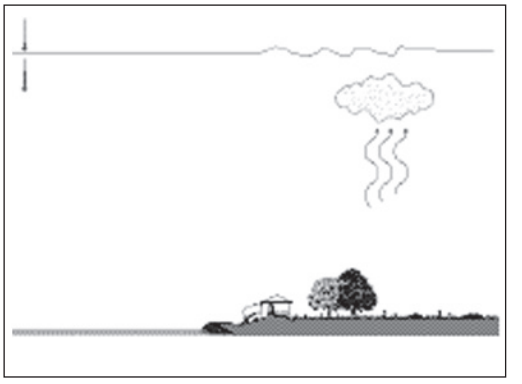
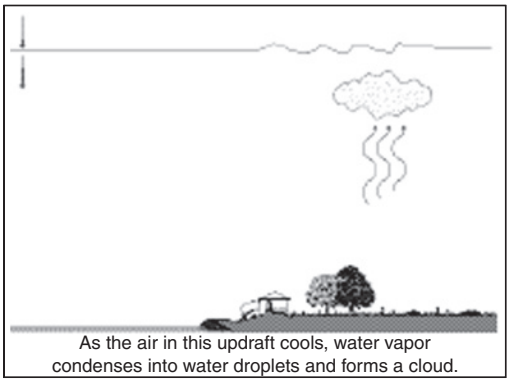
Non-redundant Presentation:
Animation and Narration



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

Redundant Presentation:
Animation, Narration, and On-Screen Text



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

Figure 12.2. *Some selected frames from nonredundant and redundant presentations on lightning.*

the words at the same time that the words are printed on the bottom of the screen. We refer to this as a redundant multimedia presentation because the same words are presented in both spoken and printed form. A shortcoming of redundant presentations is that they may induce extraneous processing, such as trying to reconcile the flow of spoken and printed words. According to the redundancy principle, students will learn more deeply from the nonredundant presentation than the redundant presentation because the redundant presentation requires more extraneous processing.

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When the surface of the earth is warm, moist air near the earth's surface becomes heated and rises rapidly, producing an updraft. As the air in these updrafts cools, water vapor condenses into water droplets and forms a cloud. The cloud's top extends above the freezing level. At this altitude, the air temperature is well below freezing, so the upper portion of the cloud is composed of tiny ice crystals.

Eventually, the water droplets and ice crystals in the cloud become too large to be suspended by updrafts. As raindrops and ice crystals fall through the cloud, they drag some of the air from the cloud downward, producing downdrafts. The rising and falling air currents within the cloud may cause hailstones to form. When downdrafts strike the ground, they spread out in all directions, producing gusts of cool wind people feel just before the start of the rain.

Within the cloud, the moving air causes electrical charges to build, although scientists do not fully understand how it occurs. Most believe that the charge results from the collision of the cloud's light, rising water droplets and tiny pieces of ice against hail and other heavier, falling particles. The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top.

The first stroke of a cloud-to-ground lightning flash is started by a stepped leader. Many scientists believe that it is triggered by a sparkbetween the areas of positive and negative charges within the cloud. A stepped leader moves downward in a series of steps, each of which is about 50-yards long, and lasts for about 1 millionth of a second. It pauses between steps for about 50 millionths of a second. As the stepped leader nears the ground, positively charged upward-moving leaders travel up from such objects as trees and buildings, to meet the negative charges. Usually, the upward moving leader from the tallest object is the first to meet the stepped leader and complete a path between the cloud and earth. The two leaders generally meet about 165-feet above the ground. Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright and usually has many branches.

As the stepped leader nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path. This upward motion of the current is the return stoke and it reaches the cloud in about 70 microseconds. The return stoke produces the bright light that people notice in a flash of lightning, but the current moves so quicklythat its upward motion cannot be perceived. The lightning flash usually consists of an electrical potential of hundreds of millions of volts. The air along the lightning channel is heated briefly to a very high temperature. Such intense heatingcauses the air to expand explosively, producing a sound wave we call thunder.

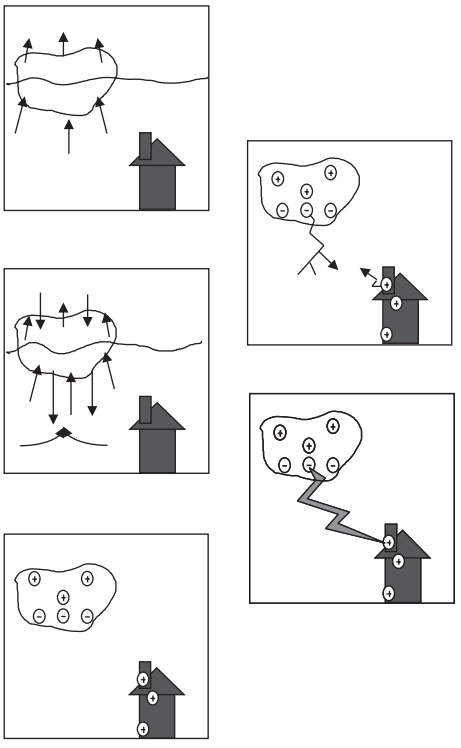

Figure 12.3. *Book-based separated presentation on lightning.*

Spatial Contiguity Techniques

Next, consider a situation in which a learner reads a booklet explaining lightning formation consisting of text on one page and illustrations on another page, as shown in Figure 12.3. This layout is an example of what we call *separated presentation* because corresponding words and pictures are far from each other. In contrast, we can reduce the need to scan back and forth between the words and pictures by creating an integrated presentation, as shown in Figure 12.1. In this layout, each illustration is placed next to the paragraph that describes it, and words from the paragraph have been inserted into the illustration, creating spatial contiguity. In this way, the learner has cues for combining corresponding words and pictures and does not have to waste cognitive processing by scanning around the page.

Temporal Contiguity Techniques

Next, consider a situation in which a learner views an animation depicting the steps in lightning formation before (or after) listening to a narration describing the same steps. In this situation, the learner has to hold all of

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the relevant images in working memory until the narration is presented (or must hold all of the relevant words in working memory until the animation is presented). The task of holding all relevant words or images in working memory – which we call *representational holding* – is likely to overload the learner's cognitive capacity, resulting in the loss of essential information. A useful way to eliminate the need for representational holding is to present corresponding words and pictures at the same time – a technique that can be called *temporal contiguity*.

What Do We Know about the Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles?

In this review, we consider articles published in archival journals or edited books in which (1) the task is an instructional lesson involving words and pictures; (2) the independent variable involves whether or not the presentation was coherent (i.e., concise vs. embellished), whether or not signals were provided (i.e., signaled vs. nonsignaled), whether or not printed words were added to narrated graphics (i.e., redundant vs. nonredundant), whether or not corresponding printed words and pictures were placed near each other on the page or screen (i.e., integrated vs. separated), and whether or not corresponding spoken words and graphics were presented at the same time (i.e., simultaneous vs. successive); (3) the dependent measure is performance on a problem-solving transfer test; and (4) reported statistics include the mean and standard deviation of each group. When the participants were broken down by prior experience, we focused on comparisons for low-experience students because low-experience students are more likely to benefit from instructional techniques that decrease extraneous processing. We computed effect size 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 (e.g., the concise group minus the embellished group, the signaled group minus the nonsignaled group, the integrated group minus the separated group, or the nonredundant group minus redundant group) and dividing by the pooled standard deviation (Cortina & Nouri, 2000). Following Cohen (1988) we consider an effect size of $d = 0.2$ to be small, $d = 0.5$ to be medium, and $d = 0.8$ to be large; and following Hattie (2009) we consider $d = 0.4$ to be educationally important.

Research on the Coherence Principle

Do people learn more deeply when extraneous words, sounds, and pictures are excluded? Table 12.4 summarizes 23 comparisons between a group that received a concise multimedia presentation (concise group) and a group that

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Table 12.4. *Evidence concerning the coherence principle*

Source	Content	Effect size
(1) Mayer et al.(1996, Exp. 1)	Lightning	−0.17
(2) Mayer et al.(1996, Exp. 2)	Lightning	0.70
(3) Mayer et al. (1996, Exp. 3)	Lightning	0.98
(4) Harp and Mayer (1997, Exp. 1)	Lightning	1.33
(5) Harp and Mayer (1998, Exp. 1)	Lightning	1.68
(6) Harp and Mayer (1998, Exp. 2)	Lightning	1.45
(7) Harp and Mayer (1998, Exp. 3)	Lightning	1.27
(8) Harp and Mayer (1998, Exp. 4)	Lightning	1.58
(9) Moreno and Mayer (2000, Exp. 1)	Lightning	1.49
(10) Moreno and Mayer (2000, Exp. 2)	Brakes	0.51
(11) Mayer, Heiser, and Lonn (2001, Exp. 3)	Lightning	0.70
(12) Mayer and Jackson (2005, Exp. 1a)	Ocean waves	0.94
(13) Mayer and Jackson (2005, Exp. 1b)	Ocean waves	0.97
(14) Mayer and Jackson (2005, Exp. 2)	Ocean waves	0.69
(15) Mayer, DeLeeuw, and Ayres (2007, Exp. 1)	Brakes	0.53
(16) Mayer, DeLeeuw, and Ayres (2007, Exp. 2)	Brakes	0.17
(17) Sanchez and Wiley (2006)	Ice age	0.97
(18) Lehman et al. (2007)	Lightning	0.78
(19) Mayer et al. (2008, Exp. 1)	Cold virus	0.80
(20) Mayer et al. (2008, Exp. 2)	Digestion	0.86
(21) Doolittle and Alstraedter (2009)	Lightning	0.06
(22) Park et al. (2011)	Biology	0.34
(23) Sung and Mayer (2012)	Distance education	1.10
Median		0.86

received the multimedia presentation with added material that was not relevant to the goal of the lesson (embellished 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.

In the first set of three comparisons listed in Table 12.4 (Mayer et al., 1996), students read a booklet explaining lightning formation and then took a transfer test. The concise booklet was a summary of the main steps of lightning formation, in the form of a series of annotated illustrations. The embellished booklet contained the same printed words and illustrations along with additional text providing details about lightning. As you can see in the first three lines of Table 12.4, students performed better on transfer tests after reading the summary than after reading the longer lesson in two out of three tests.

In a second set of five studies (Harp & Mayer, 1997, 1998), students also read a booklet about lightning formation and then took a transfer test. The

concise booklet included several paragraphs and several corresponding illustrations explaining the process of lightning formation, whereas the embellished booklet contained identical words and illustrations along with several interspersed illustrations and sentences concerning interesting stories about lightning. As in the first set of studies, students performed better on a subsequent transfer test after reading the concise rather than the embellished booklet, yielding effect sizes above $d = 1.0$ in all five comparisons. Similar results for a lightning lesson were reported by Lehman et al. (2007), as summarized in line 18.

The next three comparisons listed in Table 12.4 are based on computer-based presentations consisting of animation and narration. In one set of studies on lightning and how brakes work (Moreno & Mayer, 2000), adding background music and environmental sounds resulted in poorer transfer test performance than not having the added music and sounds (as shown in lines 9 and 10). In a study on lightning (Mayer, Heiser, & Lonn, 2001), interspersing short video clips showing lightning storms with short narration about interesting lightning facts resulted in poorer transfer test performance than not having the added clips (as shown in line 11). In contrast, as shown in line 21, Doolittle and Alstraedter (2009) found that adding extraneous sounds and animations to a multimedia lesson on lightning did not significantly hurt transfer test performance, although the authors noted that the added material may not have been sufficiently distracting.

In the next set of three comparisons, from Mayer and Jackson (2005), students learned about ocean waves by viewing either a concise or an embellished lesson in the form of a paper booklet (Exp. 1a and Exp. 1b) or narrated animation (Exp. 2). Across all experiments, the concise group outperformed the embellished group on a transfer, as shown in lines 12–14.

In two experiments by Mayer, DeLeeuw, and Ayres (2007), summarized in lines 15 and 16, students learned how hydraulic brakes work from a concise or embellished version of a computer-based or paper-based lesson. The expanded version of the lesson included multimedia explanations of similar physical systems (how caliper brakes work and how air brakes work) presented after (Exp. 1) or before (Exp. 2) the explanation of hydraulic brakes. The concise group generally outperformed the embellished group on transfer tests, although the effect was stronger when the extraneous material came after the target lesson than when it came before.

In a study by Sanchez and Wiley (2006), students learned about the causes of ice ages by viewing a lesson that contained either relevant, conceptual illustrations or irrelevant, seductive illustrations. The results indicated a seductive details effect for students with a low working memory capacity on an argumentative essay ($d = 1.14$) and an inference verification task ($d = 0.81$), as shown in line 17; however, there was no seductive details effect for students with a high working memory capacity.

Lines 19 and 20 summarize a set of studies by Mayer et al. (2008) in which adding high-interest extraneous details (e.g., about sex, death, or filth)

to a multimedia lesson on how a cold virus causes a cold (Exp. 1) or how the human digestive system works (Exp. 2) resulted in lower transfer test performance.

In Park et al. (2011), high school students learned about the structure and function of a cellular molecule involved in ATP synthesis from an animated lesson that included seductive details or did not include seductive details and that either imposed high cognitive load (i.e., on-screen text) or low cognitive load (i.e., spoken narration). The results indicated no significant main effect of seductive details on a transfer test ($d = 0.34$, favoring the no-details group, as shown in line 22). However, there was a significant interaction between the details group and cognitive load, such that seductive details may foster learning under low-load conditions ($d = 0.93$) but not under high-load conditions ($d = -0.08$).

Finally, in a study by Sung and Mayer (2012) Korean college students learned about the history of distance education from a computer-based lesson that included instructive graphics, decorative graphics, or seductive graphics. The instructive group outperformed the seductive group ($d = 1.13$, as shown in line 23) and the decorative group ($d = 0.61$) on a subsequent test.

Overall, there is strong and consistent evidence for the *coherence principle*: people learn more deeply from a multimedia message when extraneous material is excluded rather than included. In most comparisons in Table 12.4, there is a large positive effect size favoring the concise group, and the median effect size of $d = 0.86$ is large. These results show that coherence is important in both paper-based and computer-based presentations. In a recent meta-analysis of the seductive details effect, Rey (2012) reported a median effect size of $d = 0.65$ favoring the exclusion of extraneous text across four comparisons involving transfer tests and $d = 0.83$ for exclusion of extraneous illustrations across 12 experiments involving transfer tests.

Concerning boundary conditions, there is preliminary evidence that the coherence effect may be affected by the learner's working memory capacity (Sanchez & Wiley, 2006; see also Chapter 25), the cognitive load imposed by the learning task (Park, Moreno, Seufert, & Brünken, 2011), or the level of interestingness of the extraneous material (Mayer et al., 2008). Similarly, Rey (2012) reported that the coherence effect was stronger for learners with a low working memory capacity than for learners with a high working memory capacity, when the lesson was system-paced rather than learner-paced, and when the extraneous material was highly distracting rather than neutral. In short, extraneous material is most damaging when it is most likely to increase cognitive load beyond the learner's cognitive capacity.

Research on the Signaling Principle

If it is not possible to delete extraneous material, an alternative way to reduce extraneous processing is to provide signals to the learner showing

what should be attended to. Table 12.5 lists 28 tests of the signaling principle; lines 5–12 involve verbal signaling (i.e., key words are highlighted), while the first 4 lines and the last 16 lines involve visual signaling or cueing (i.e., key elements in the graphic are highlighted).

The first four lines summarize the results of a classic set of studies by Jeung, Chandler, and Sweller (1997) in which students learned how to solve geometry problems by viewing worked examples in the form of narrated graphics presented on a computer screen. Highlighting relevant portions of the screen by flashing resulted in better transfer test performance when the display was complex (Exp. 1a) but not when the display was simple (Exp. 1b).

The next set of eight studies involves verbal signaling. In the first verbal signaling study (Harp & Mayer, 1998), some students (nonsignaled group) read a paper-based lesson on lightning such as described in the preceding section and then took a transfer test. For other students (signaled group), the text was modified by the addition of an organizational sentence listing the seven main steps and then the insertion of numbers such as "(1)" to correspond to each step as it was described in the lesson. As shown in line 5 of Table 12.5, this form of signaling produced a small-to-medium effect size.

In the second set of two studies (Mautone & Mayer, 2001), some students (nonsignaled group) received a narrated animation explaining how an airplane achieves lift and then took a transfer test. Other students (signaled group) received the same instruction and test, except that the narration was signaled – that is, the narrator began by listing the three steps, and the narrator inserted a heading sentence before each section. Signaling benefited the students, yielding medium-to-large effect sizes, as shown in lines 6 and 7.

In three experiments by Stull and Mayer (2007), students learned about the reproductive barriers between species by reading a lesson that either included or did not include graphic organizers in the margin of the text that were intended to highlight and organize the essential words in the text. In Experiment 1, twenty-seven graphic organizers were used and there was no signaling effect on transfer tests ($d = -0.03$ in line 8). In Experiments 2 and 3, eighteen and ten graphic organizers were used respectively, and there was a signaling effect (Exp. 2: $d = 0.58$ in line 9; Exp. 3: $d = 0.45$ in line 10), suggesting that signaling should be used in moderation.

In Naumann et al. (2007), college students with either low or high reading skill learned about how visual perception works by reading expository hypertexts that either included hypertext-specific signaling (signaling group) or consisted only of linear text (nonsignaling group). In two experiments, a signaling effect was found for low-skill readers on an essay-based transfer test (Exp. 1: $d = 0.42$; Exp. 2: $d = 0.65$), as shown in lines 11 and 12, but there was no signaling effect for high-skill readers (Exp. 1: $d = -0.12$; Exp. 2: $d = -0.31$).

The remaining studies in Table 12.5 involve visual signaling that goes beyond the flashing technique used by Jeung, Chandler, and Sweller (1997). In

Table 12.5. *Evidence concerning the signaling principle (or cueing principle)*

Source	Content	Effect size
(1) Jeung, Chandler, and Sweller (1997, Exp. 1a)	Geometry	0.63
(2) Jeung, Chandler, and Sweller (1997, Exp. 1b)	Geometry	−0.14
(3) Jeung, Chandler, and Sweller (1997, Exp. 2)	Geometry	0.08
(4) Jeung, Chandler, and Sweller (1997, Exp. 3)	Geometry	0.13
(5) Harp and Mayer (1998, Exp. 3a)	Lightning	0.34
(6) Mautone and Mayer (2001, Exp. 3a)	Airplane	0.60
(7) Mautone and Mayer (2001, Exp. 3b)	Airplane	0.70
(8) Stull and Mayer (2007, Exp. 1)	Biology	−0.03
(9) Stull and Mayer (2007, Exp. 2)	Biology	0.58
(10) Stull and Mayer (2007, Exp. 3)	Biology	0.45
(11) Naumann et al. (2007, Exp. 1, low skill)	Visual perception	0.42
(12) Naumann et al. (2007, Exp. 2, low skill)	Visual perception	0.65
(13) Mautone and Mayer (2007)	Geography	0.50
(14) de Koning et al. (2007)	Cardiovascular system	0.81
(15) Kriz and Hegarty (2007)	Mechanical system	0.24
(16) Moreno (2007, Exp. 1)	Teaching skills	0.27
(17) Moreno (2007, Exp. 2)	Teaching skills	0.32
(18) Jamet et al. (2008)	Language production	−0.07
(19) Doolittle and Alstraedter (2009)	Brakes	0.04
(20) Boucheix and Lowe (2010, Exp. 1a)	Piano	0.75
(21) Boucheix and Lowe (2010, Exp. 1b)	Piano	−0.03
(22) de Koning et al. (2010)	Cardiovascular system	0.37
(23) Ozcelik et al. (2010)	Jet engine	0.74
(24) Rey (2010)	Neural networks	0.41
(25) Scheiter and Eitel (2010)	Heart	0.85
(26) Amadieu et al. (2011)	Biology	0.63
(27) Boucheix (2013)	Piano	0.80
(28) Jarodzka et al. (2013)	Fish locomotion	0.35
Median		0.41

a visual signaling (or cueing) study by Mautone and Mayer (2007), students learned about fluvial processes in geography by viewing scientific graphs that included signaling or no signaling. When asked to write explanations of each graph, the signaling group generated more relational statements about the lesson than the nonsignaling group ($d = 0.95$), but the two groups did not differ significantly in the number of causal statements they generated ($d = 0.05$), so line 13 presents the average (d = 0.50). In de Koning et al. (2007), shown in line 14, students who learned about the human cardiovascular system from a computer-based animation that contained visual cues (i.e., spotlighting key processes) performed better on a transfer test than students who did not receive cueing. A follow-up study by de Koning et al. (2010) yielded smaller, nonsignificant cueing effects, as shown in line 22.

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In contrast, some studies have revealed only small, nonsignificant effects of visual cueing or none at all. Kriz and Hegarty (2007) found that students who learned about how a mechanical system works by viewing an animation that contained signaling with arrows performed only slightly better on a comprehension test than those receiving no signaling (as shown in line 15), although eye-tracking data indicated that signaling directed students' attention to the relevant areas of the animation. In two experiments by Moreno (2007), pre-service teachers learned about seven essential teaching skills by viewing a classroom video (Exp. 1) or a computer-based animation (Exp. 2) that either included signaling or did not include signaling. The signaling group did not differ significantly from the nonsignaling group on transfer tests and produced only small signaling effects (as shown in lines 16 and 17). In a study by Jamet, Govota, and Quaireau (2008), summarized in line 18, students who learned about the cerebral basis of language production from a computer-based narrated lesson did not show better transfer test performance when the lesson included signaling in the form of color change for the described elements. In Doolittle and Alstraedter (2009), shown in line 19, students who received a narrated animation on a car's braking system did not perform better on a transfer test when signaling was included in the form of spotlighting key aspects of the animation.

In Boucheix and Lowe (2010), students learned about how a piano system works from animations in which spreading-color cues aided performance across a variety of transfer tests ($d = 0.75$) but arrow cues did not ($d = -0.03$), as summarized in lines 20 and 21. In a follow-up study summarized in line 23, Boucheix et al. (2013) found that cues emphasizing a progressive path aided transfer performance ($d = 1.42$) better than cues that highlighted a sequence of individual entities ($d = 0.21$).

In Ozcelik, Arslan-Ari, and Cagiltay (2010), students who learned how turbofan jet engines work from a computer-based multimedia lesson that was signaled (i.e., colors of labels to illustrations temporarily changed) outperformed a nonsignaled group on a transfer test, as shown in line 23. In a study by Rey (2010), shown in line 24, students who learned about causal connections of neural networks within a computer simulation performed better on a transfer test if the lesson included signaling.

As summarized in line 25, Scheiter and Eitel (2010) reported that students who learned about the functioning of the human heart from a signaled version of a computer-based multimedia lesson outperformed those who received a nonsignaled version on questions involving text–diagram integration. In Amadieu, Marine, and Lemay (2011), summarized in line 26, students performed better on a problem-solving test when they learned about the process of synapsis from a computer-based animation that contained cueing, which zoomed in on important information at each stage of the process, rather than no cueing.

Finally, as summarized in line 28, Jarodzka et al. (2013) asked students to learn about the classification of fish locomotion from a video that included

modeling of an expert's eye movements (i.e., in the form of either a dot on the screen or a spotlight) or that did not include eye movement modeling. Overall, participants receiving eye movement modeling were better able to identify which parts of a fish's body are involved in producing propulsion (d = 0.46), but they were not significantly better at identifying how these parts move (d = 0.23).

Overall, Table 12.5 shows support for the *signaling principle*: people learn more deeply from a multimedia message when the text is signaled rather than nonsignaled. The signaling principle was supported in 24 out of 28 tests, yielding a median effect size of 0.41, which according to Hattie (2009) is considered to have an educationally important impact. Verbal forms of signaling as summarized in lines 5–12 of Table 12.5 tend to produce medium effect sizes, yielding a median effect size of d = 0.50. When we focus solely on visual signals (or cueing) represented in lines 1–4 and 13–28, the median effect size is d = 0.36, with stronger effects for certain forms of cueing such as spreading color and weaker effects for other forms such as arrows. In a review of visual cueing research, de Koning, Tabbers, Rikers, and Paas (2009) concluded that visual cues are most effective when they guide attention both spatially and temporally and that some cues may guide attention, some may emphasize organization, and some may highlight relations (corresponding respectively to the cognitive processes of selecting, organizing, and integrating in the cognitive theory of multimedia learning). Clearly, more work is needed on pinpointing which aspects of visual signaling (or cueing) are most effective for which cognitive functions. Some of these issues are examined in Chapter 11 on the signaling principle.

Concerning boundary conditions, there is preliminary evidence that the signaling principle applies more strongly to low-knowledge learners than high-knowledge learners (Naumann et al., 2007), when it is used sparingly rather than excessively (Stull & Mayer, 2007), and when the display is complex rather than simple (Jeung, Chandler, & Sweller, 1997). In short, when students may otherwise be overloaded with extraneous processing, signaling can free up cognitive capacity for essential and generative processing.

Research on the Redundancy Principle

Another way to reduce extraneous cognitive load for narrated animations (or narrated graphics) is to refrain from adding redundant on-screen text (or on-page printed text). Table 12.6 summarizes 16 experimental tests of the redundancy principle. The first two lines are based on classic studies by Mousavi, Low, and Sweller (1995) in which secondary school students learned to solve geometry proof problems through worked examples. Some students (redundant group) received worked examples in the form of a sheet with printed diagrams and printed words, as well as an audio message with spoken words that were identical to the printed words. Other students

Table 12.6. *Evidence concerning the redundancy principle*

Source	Content	Effect size
(1) Mousavi, Low, and Sweller (1995, Exp. 1)	Math problems	0.65
(2) Mousavi, Low, and Sweller (1995, Exp. 2)	Math problems	0.49
(3) Kalyuga, Chandler, and Sweller (1999, Exp. 1)	Electrical engineering	1.38
(4) Kaluga, Chandler, and Sweller (2000, Exp. 1)	Electrical engineering	0.86
(5) Craig, Gholson, and Driscoll (2002, Exp. 2)	Lightning	0.67
(6) Mayer, Heiser, and Lonn (2001, Exp. 1)	Lightning	0.88
(7) Mayer, Heiser, and Lonn (2001, Exp. 2)	Lightning	1.21
(8) Moreno and Mayer (2002b, Exp. 2)	Lightning	0.72
(9) Moreno and Mayer (2002a, Exp. 2a)	Botany game	0.19
(10) Moreno and Mayer (2002a, Exp. 2b)	Botany game	0.25
(11) Leahy, Chandler, and Sweller (2003)	Temperature graphs	1.13
(12) Jamet and Le Bohec (2007)	Human memory	0.67
(13) Austin (2009, Exp. 1)	Lightning	0.87
(14) Austin (2009, Exp. 2)	Lightning	1.15
(15) Austin (2009, Exp. 3)	Lightning	1.80
(16) Austin (2009, Exp. 4)	Lightning	1.91
Median		0.86

(nonredundant group) received worked examples in the form of a sheet with printed diagrams and an audio message with spoken words. On a subsequent test of solving a transfer problem, the nonredundant group outperformed the redundant group, yielding effect sizes in the medium range.

The next two lines of Table 12.6 are based on studies by Kalyuga, Chandler, and Sweller (1999, 2000) in which trainees learned electrical engineering topics. Some students were given a computer presentation containing a printed diagram on the screen and an audio message with spoken words (nonredundant group), whereas other students were given a computer presentation containing a printed diagram and printed text on the screen along with an audio message with spoken words that were identical to the printed words (redundant group). On a subsequent problem-solving transfer test, the nonredundant group outperformed the redundant group, yielding high effect sizes. In the second study, shown in line 4, the detrimental effects of adding redundant text were obtained for low-experience learners only. High-experience learners may have so much free processing capacity that they did not suffer from processing redundant materials.

The next four lines of Table 12.6 summarize studies (Craig, Gholson, & Driscoll, 2002; Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002b) in which students viewed a narrated animation on lightning formation (nonredundant group) or the same narrated animation along with redundant on-screen text (redundant group). In each comparison, the nonredundant group performed better than the redundant group on a problem-solving transfer test, with effect sizes in the medium to large range.

The next two lines summarize studies by Moreno and Mayer (2002a) involving a botany game in which the game was presented on a desktop computer (line 9) or via a head-mounted display in virtual reality (line 10). As part of the game, some students viewed animations and heard concurrent explanations (nonredundant group), whereas others viewed animations, heard concurrent explanations, and also saw on-screen text that was identical to the spoken explanations (redundant group). The nonredundant group performed better than the redundant group, but the effect sizes were small.

Line 11 summarizes a study by Leahy, Chandler, and Sweller (2003) in which elementary school children learned to use temperature graphs to answer questions. Transfer test performance was better when students viewed a graph with printed text (nonredundant group) than when they received the same graph with printed text along with concurrent audio commentary (redundant group). In this case, a redundancy effect was obtained when spoken words were added to printed words and graphics, perhaps because students had unlimited time to process the printed words and graphics.

In a study by Jamet and Le Bohec (2007) summarized in line 12, students learned about memory functioning from a computer-based multimedia lesson that presented words in both spoken and text form (redundant group) or only in spoken form (nonredundant group). The nonredundant group outperformed the redundant group on a transfer test. In a follow-up study, Le Bohec and Jamet (2008) obtained similar results for a lesson on accounting principles when students were not allowed to take notes but not when they were allowed to take notes; however, insufficient statistical information was provided to allow for computation of effect size needed for inclusion in the table.

Finally, in four experiments by Austin (2009), students learned about the formation of lightning by viewing a short animated narration or an animated narration with corresponding text. The group that viewed the animated narration outperformed the group that viewed the animated narration with text on a transfer test in all experiments, as summarized in the last four lines of Table 12.6.

Rockwell and Singleton (2007) also reported that students scored higher on a comprehension test after receiving printed text about the nation of Mali than from text, audio, and video, but insufficient information was given to compute effect size for inclusion in Table 12.6. In a somewhat different way of creating redundancy, also not included in Table 12.6 because it does not involve the typical comparison, Liu et al. (2012) taught fifth grade students about the leaf morphology of plants from a mobile device consisting of embedded text and pictures (TP group) or text and pictures embedded in the device and a real object outside of the device (TPO group). Consistent with the redundancy effect, the TP group outperformed the TPO group on a comprehension test ($d = 0.56$).

Overall, there is consistent support for the redundancy principle: people learn more deeply from graphics and narration than from graphics, narration, and on-screen text. In all 16 tests, the nonredundant group outperformed the redundant group on tests of problem-solving transfer, yielding a median effect size of $d = 0.86$. The redundancy principle described in this chapter involves a specific situation in which the narration (the spoken words) and the on-screen text (the printed words) are identical. The redundancy principle described in this chapter represents a subset of Sweller and Kalyuga's redundancy principle as described in Chapter 10. In Chapter 10, Sweller and Kalyuga define redundancy as occurring when "the same information is presented in multiple forms or is unnecessarily elaborated." This definition includes what we call redundancy (this chapter) and coherence (this chapter), as well as situations in which words and graphics convey the same information (not addressed in this chapter).

Three important boundary conditions are that the redundancy effect can be eliminated or even reversed when the learners are experienced, the on-screen text is short, or the material lacks graphics. First, as noted previously, Kalyuga, Chandler, and Sweller (1999, 2000) found that low-experience learners produced a redundancy effect but high-experience learners did not, consistent with the expertise reversal principle described in Chapter 24. An explanation for this boundary condition is that high-experience learners may be less likely to be overloaded by the redundant material because they have strategies for organizing it, which reduces overall cognitive load.

Second, consider why it might be useful to present a few printed words next to the corresponding part of a graphic in a narrated animation or slideshow. In this case, the words may not be enough to distract the learner from the graphic and may even signal where to look, while also helping to reinforce the main verbal content. To test this idea, Mayer and Johnson (2008) asked students to learn about lightning formation (Exp. 1) or how a car's brake system works (Exp. 2) by viewing a narrated multimedia presentation (nonredundant group) or by viewing the same narrated multimedia presentation with a key word or phrase printed next to the corresponding part of the graphic (redundant group). In both experiments, the redundant group outperformed the nonredundant group on a retention test (Exp. 1: $d = 0.47$; Exp. 2: $d = 0.70$), but there was no difference in performance between the groups on the transfer test (Exp. 1: $d = 0.04$; Exp. 2: $d = 0.15$).

Finally, consider why the redundancy effect can disappear when no graphics are presented. In this case, adding on-screen text does not create split attention (i.e., the need to visually span between printed words and graphics) because there is no other material to process in the visual channel. For example, Moreno and Mayer (2002a) reported that verbal redundancy (i.e., adding spoken text to printed text) aided learning when the verbal material was short (e.g., a sentence at a time). In a recent meta-analysis of research on verbal redundancy, Adesope and Nesbit (2012) reported that students

learned better from spoken and printed words than from spoken words alone when there were no graphics in the lesson ($d = 0.24$), but not when there was a concurrent animation along with the printed and spoken words ($d = 0.06$). Finally, verbal redundancy can hurt learning of a second language when the verbal material is lengthy (Diao & Sweller, 2006) or when the goal is to learn to read in a second language (Diao, Chandler, & Sweller, 2007).

Research on the Spatial Contiguity Principle

Another way to reduce extraneous processing is to guide the learner's cognitive processing by placing printed words near the graphics they describe. Table 12.7 summarizes the results of 22 tests of the spatial contiguity principle. In the first study listed (Mayer, 1989), students read a paper-based lesson on how brakes work and then took a transfer test. For some students (integrated group), the words describing an action – such as the piston moving forward in the master cylinder – were placed next to the corresponding part of an illustration – such as the master cylinder. For other students (separated group), each picture was at the top of a page and the corresponding words were in a paragraph at the bottom of the page. The integrated group performed much better than the separated group on a transfer test, yielding an effect size above $d = 1.0$.

Line 2 in Table 12.7 summarizes a study by Sweller, Chandler, Tierney, and Cooper (1990) in which students learned to solve geometry problems by examining worked examples. In the integrated booklet, the text and symbols describing each step were placed next to the corresponding part of the geometry diagram, whereas in the separated booklet, the text and symbols describing each step were placed below the geometry diagram. The time required to solve a transfer problem was less for students who learned with the integrated booklet than for those who learned with the separated booklet, yielding a medium to high effect size. Sweller, Chandler, Tierney, and Cooper (1990) and Tarmizi and Sweller (1988) reported similar results in other experiments as well, but these experiments are not included in Table 12.7 because the means and standard deviations on transfer tests were not reported.

Line 3 summarizes a study in which trainees learned about topics in electrical engineering from an integrated or separated booklet and later were asked to solve practical problems (Chandler & Sweller, 1991, Exp. 1). In the integrated booklet, text describing each step in a procedure was placed next to the corresponding element in a diagram, whereas in the separated booklet the words were on the top of the sheet and the diagram was on the bottom. In a related study (Chandler & Sweller, 1991, Exp. 6), shown in line 4, students learned about the human heart by viewing a diagram with 12 numbered steps, each printed next to its corresponding part in the diagram (integrated group) or in a legend (separated group). In both experiments, the integrated group outperformed the separated group, and in a follow-up

Table 12.7. *Evidence for the spatial contiguity principle*

Source	Content	Effect size
(1) Mayer (1989, Exp. 2)	Brakes	1.36
(2) Sweller et al. (1990, Exp. 1)	Mathematics problems	0.71
(3) Chandler and Sweller (1991, Exp. 1)	Electrical engineering	0.41
(4) Chandler and Sweller (1991, Exp. 6)	Heart	0.60
(5) Chandler and Sweller (1992, Exp. 1)	Electrical engineering	1.19
(6) Mayer et al. (1995, Exp. 1)	Lightning	1.09
(7) Mayer et al. (1995, Exp. 2, low knowledge)	Lightning	1.35
(8) Mayer et al. (1995, Exp. 3)	Lightning	1.12
(9) Tindall-Ford et al. (1997)	Electrical engineering	1.08
(10) Moreno and Mayer (1999)	Lightning	0.82
(11) Bodemer et al. (2004, Exp.1)	Tire pump	0.56
(12) Bodemer et al. (2004, Exp. 2)	Statistics	0.22
(13) Kester et al. (2005)	Electrical circuits	0.78
(14) Chung (2007, Exp. 1)	Chinese vocabulary	2.06
(15) Chung (2007, Exp. 2)	Chinese vocabulary	1.56
(16) Pociask and Morrison (2008)	Medical procedures	1.26
(17) Owens and Sweller (2008)	Musical notation	0.62
(18) Austin (2009)	Lightning	1.39
(19) Cierniak et al. (2009)	Kidney	1.11
(20) Johnson and Mayer (2012, Exp. 1)	Brakes	0.80
(21) Johnson and Mayer (2012, Exp. 2)	Brakes	0.73
(22) Johnson and Mayer (2012, Exp. 3)	Brakes	0.35
Median		1.10

study (line 5) involving electrical engineering, Chandler and Sweller (1992) reported similar results. Sweller and Chandler (1994) found similar results with a booklet on computer programming, but these results were not included in Table 12.7 because the separated treatment required information provided on a computer screen as well as information in a booklet.

Lines 6–8 show three comparisons in which students read an integrated or separated booklet on lightning formation and then took a transfer test (Mayer et al., 1995). For the integrated booklet, each illustration was placed next to the paragraph that described it, and each illustration had a summary caption that contained words selected from the corresponding paragraph. For the separated booklet, the printed words were on a different page than the illustrations. In each of three comparisons, students performed better on the transfer test if they had read the integrated booklet rather than the segregated booklet, with effect sizes greater than 1 in each case.

In a follow-up study involving a computer-based animation with on-screen text (Moreno & Mayer, 1999), the on-screen text was placed either near the corresponding element in the animation (integrated group) or at the bottom

of the screen (separated group). As shown in the line 10, students performed better on the transfer test if they had received the integrated presentation rather than the segregated presentation, with an effect size of greater than $d = 0.80$. Similar results with animated lessons on lightning were obtained by Austin (2009), as reported in line 18.

Tindall-Ford, Chandler, and Sweller (1997) asked apprentices to read a booklet on topics in electrical engineering and then solve some practical problems. Some apprentices read an integrated booklet in which text describing each step in a procedure was placed next to the corresponding part of a diagram; others read a separated booklet in which the text was presented below the corresponding diagram. As shown in line 9 of Table 12.7, the integrated group performed better on solving practical problems than did the separated group, yielding an effect size of greater than $d = 1.0$.

Line 11 summarizes a study by Bodemer, Ploetzner, Feuerlein, and Spada (2004) in which students received a computer-based lesson on how a bicycle tire pump works. The lesson consisted of diagrams showing the pump with the handle up and with the handle down along with 15 numbered captions placed either next to the corresponding parts of the diagrams (integrated group) or in a legend at the bottom (separated group). The integrated group outperformed the separated group on a transfer test. In a follow-up study involving statistics (in line 12), a similar pattern was found, although the effect was weaker, perhaps because "even the integrated format still required a considerable amount of visual search" (Bodemer et al., 2004, p. 336).

In a study by Kester, Kirschner, and van Merriënboer (2005), high school students learned about electrical circuits from either an integrated or a nonintegrated computer-based lesson. No differences in performance were found between the groups on problems that were equivalent to those practiced during training; however, the integrated group outperformed the nonintegrated group on problems requiring students to apply their knowledge to new situations, as shown in line 13.

In a study by Chung (2007), high school students learned the translation of Chinese characters by viewing cards with the English word adjacent to the character or far away. In two experiments (lines 14 and 15), the adjacent group outperformed the far-away group on both immediate and delayed measures of word meaning and pronunciation.

In a study by Pociask and Morrison (2008), first-year physical therapy graduate students learned about physical therapy procedures by viewing either a traditionally designed lesson, which included redundant and split-attention features (control group), or a modified lesson, which removed these features by physically integrating related elements of information (modified group). The modified group outperformed the control group on a written post-test that consisted of knowledge, comprehension, analysis, synthesis, and evaluation questions, as summarized in line 16.

In a study by Owens and Sweller (2008), seventh grade students learned about musical notation by viewing a lesson that consisted of separated text and diagrams or integrated text and diagrams. The integrated group outperformed the separated group on a transfer test, as shown in line 17.

In a study by Cierniak, Scheiter, and Gerjets (2009), students learned about the physiological processes of the kidney by viewing a computer-based lesson that contained text and diagrams that were spatially separated or text and diagrams that were spatially integrated. The integrated group outperformed the separated group on an inference test, as summarized in line 19.

Finally, in three experiments by Johnson and Mayer (2012), summarized in lines 20–22, students learned about how a car's brake system works by viewing a single-slide multimedia presentation that consisted of words either separated from or integrated with a corresponding diagram. The integrated group outperformed the separated group in Experiment 1 (d = 0.80) and Experiment 2 (d = 0.73) but not significantly in Experiment 3 (d = 0.35). Further, eye-tracking analysis revealed that the integrated group had significantly more eye movements between the text and the diagram (i.e., integrative transitions) across all three experiments.

In all 22 cases listed in Table 12.7 the effect sizes favored integrated presentation, yielding a median effect size of greater than 1. A meta-analysis by Ginns (2006) also showed strong evidence for the spatial contiguity effect, yielding a large mean effect size of d = 0.72 across 37 experiments. Thus, there is strong and consistent support for the spatial contiguity principle: people learn more deeply from a multimedia message when corresponding text and pictures are presented near rather than far from each other on the page or screen.

The spatial contiguity principle represents a subset of what Ayres and Sweller call the *split-attention principle* in Chapter 8. The split-attention principle refers to "avoiding formats that require learners to split their attention between, and mentally integrate, multiple sources of information" and includes what we refer to as spatial contiguity (described in this section), temporal contiguity (described in the next section), and situations in which students must use different multiple delivery systems such as both a computer-based lesson and a paper-based lesson (which we do not cover in this chapter).

Four possible boundary conditions for the spatial contiguity principle involve the idea that the principle is strongest for learners with low prior knowledge, nonredundant text and pictures, complex lessons, and interactive formats. First, Mayer and colleagues (1995, Exp. 2) reported that integrated presentations were more effective than separated presentations for low-knowledge learners but not for high-knowledge learners, consistent with the expertise reversal principle, as described in Chapter 24. Line 7 in Table 12.7 is based on learners with low prior knowledge (low knowledge).

Second, Ayres and Sweller (in Chapter 8) noted that the spatial contiguity principle applies mainly when multiple sources of information would be unintelligible in isolation. In short, if the words are not needed to understand the graphic, it does not matter if the words are presented in separated format. Third, Ayres and Sweller (in Chapter 8) also noted that the spatial contiguity principle applies when the material is complex, but may not apply when the material is so simple that separated design does not overload the cognitive system. Finally, Bodemer and colleagues (2004) provide some evidence that the spatial contiguity principle can be strengthened when learners create integrated presentations by moving text to relevant portions of a graphic on tire pumps.

Research on the Temporal Contiguity Principle

Does presenting corresponding words and pictures at the same time foster deeper understanding than presenting them successively? Table 12.8 summarizes the results of nine tests of the temporal contiguity principle, in which the lesson is long (i.e., more than a sentence or two) and continuous (i.e., without learner control of the pace) and the test involves transfer (i.e., more than remembering presented facts). The first set of two studies listed in Table 12.8 involve learning from a narrated animation explaining how a tire pump works (Mayer & Anderson, 1991). For some learners (simultaneous group), the words of the narration were synchronized with the events depicted in the animation, so that, for example, when the narrator said, "The inlet valve opens," the animation showed the inlet valve opening. For other learners (successive group), the entire narration was presented either before or after the entire animation. On subsequent tests of problem-solving transfer, the simultaneous group outperformed the successive group. Similar results were with narrated animations concerning tire pumps and brakes (Mayer & Anderson, 1992), tire pumps and the human respiratory system (Mayer & Sims, 1994), and lightning and brakes (Mayer, Moreno, Boire, & Vagge, 1999). Finally, line 9 summarizes a study by Owens and Sweller (2008), in which seventh grade students learned about musical notation by viewing a lesson that consisted of either the successive or simultaneous presentation of written text and auditory musical excerpts accompanying musical notations. The simultaneous group outperformed the successive group on a transfer test. In all nine cases the effect sizes were large, yielding a median effect size of $d = 1.22$. Thus, there is strong and consistent support for the temporal contiguity principle: people learn more deeply from a multimedia message when corresponding animation and narration are presented simultaneously rather than successively.

Consistent with the evidence summarized in Table 12.8, a meta-analysis by Ginns (2006) gave strong evidence for the temporal contiguity effect, yielding a mean effect size of $d = 0.78$ across 13 experiments. Similar research on

Table 12.8. *Evidence concerning the temporal contiguity principle*

Source	Content	Effect size
(1) Mayer and Anderson (1991, Exp. 1)	Tire pump	0.92
(2) Mayer and Anderson (1991, Exp. 2a)	Tire pump	1.14
(3) Mayer and Anderson (1992, Exp. 1)	Tire pump	1.66
(4) Mayer and Anderson (1992, Exp. 2)	Brakes	1.39
(5) Mayer and Sims (1994)	Tire pump	0.91
(6) Mayer and Sims (1994)	Lungs	1.22
(7) Mayer et al. (1999, Exp. 1)	Lightning	2.22
(8) Mayer et al. (1999, Exp. 2)	Brakes	1.40
(9) Owens and Sweller (2008)	Musical notation	0.86
Median		1.22

temporal contiguity is also reviewed by Ayres and Sweller in Chapter 8 on the split-attention principle. Split attention refers to the need to integrate material from disparate sources, which is a broader concept than temporal contiguity.

Research based on recall tests produces results similar to those obtained with transfer tests. Classic research by Baggett and colleagues also showed that students remembered more facts from a movie on carnivorous plants (Baggett & Ehrenfeucht, 1983) or a movie showing how to construct a toy (Baggett, 1984) when a narrated explanation was concurrent rather than successive, although no transfer tests were given. Similarly, students performed better on a cued recall test of presented facts when they saw verbal facts about fictitious stellar constellations presented on the same slide as a pictorial depiction than when the verbal and pictorial information was presented sequentially (Rummer et al., 2011). Finally, Tiene (2000) asked students to listen to a list of 15 facts about a fictitious island while viewing a line-drawing map of the island (simultaneous group) or before or after seeing the map (successive group). Recall test performance was better for simultaneous presentation when the words were spoken (as consistent with the temporal contiguity principle) but worse when the words were printed (perhaps because visual presentation of printed words and the map from two different sources at the same time produced split attention).

The boundary conditions for the temporal contiguity principle include spatial ability, learner control, and lesson length. First, concerning spatial ability, the results reported by Mayer and Sims (summarized in Table 12.8) hold for high-spatial learners but not for low-spatial learners, suggesting that low-spatial learners are less able to take advantage of improvements in temporal contiguity. Lines 5 and 6 are based on high-spatial learners. Second, concerning learner control, Michas and Berry (2000) asked college students to view a series of seven slides on a computer screen showing steps in a

bandaging procedure along with concurrent on-screen text (simultaneous group) or with seven text slides presented before or after the drawings (successive presentation). Learners could control the pace and order of the presentation by clicking on "next" or "previous" or "go to start" buttons. In this study, the temporal contiguity effect was negligible, suggesting that a possible boundary condition is that the lesson must be fast-paced and under system control. Third, several researchers have found that the temporal contiguity principle can be eliminated or even reversed when the material is presented in small chunks that do not exceed working memory capacity, such as one frame of the lightning passage preceded or followed by one line of text (Mayer et al., 1999, Exps. 1 & 2; Moreno & Mayer, 1999, Exp. 2; Schuler, Scheiter, Rummer, & Gerjets, 2012). Similarly, Ginns (2006) reported that a possible moderating variable for the temporal contiguity principle may be the complexity of the material, with strong effects mainly for complex lessons.

What Are the Implications of Research for Cognitive Theory?

The research results summarized in Tables 12.4–12.8 provide support for the predictions of the cognitive theory of multimedia learning as summarized in Figure 3.2 of Chapter 3. When learners have to waste some of their precious cognitive resources on processing extraneous material, they must allocate less cognitive processing to making sense of the essential material, and thus may not be able to build meaningful learning outcomes. In short, when they are prevented from cognitively processing the essential material, their learning outcomes suffer – as indicated by tests of problem-solving transfer.

According to the cognitive theory of multimedia learning, five ways to handle an extraneous overload situation are to eliminate extraneous material (coherence principle), insert signals emphasizing the essential material (signaling principle), eliminate redundant printed text (redundancy principle), place printed text next to corresponding parts of graphics (spatial contiguity principle), and eliminate the need to hold essential material in working memory for long periods of time (temporal contiguity principle). In each case, the guiding premise is that *less is more* – that is, learners benefit when they can focus on processing the essential material rather than processing both essential and extraneous material. With the coherence and redundancy principles, the extraneous material is eliminated; with the signaling and spatial contiguity principles, typographic and linguistic cues draw learners' attention to the essential material; with temporal contiguity, the need for holding material in working memory for extended periods is eliminated. 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 as well as support for the predictions of the cognitive theory of multimedia learning.

What Are the Implications of Research for Instructional Design?

The research reviewed in this chapter shows that instructional designers should be sensitive to the limitations of working memory by being careful about the amount and layout of information that is presented to learners. That is, instructional designers should work hard to minimize the amount of unneeded detail in the graphical and textual material in multimedia messages. Extraneous material should be ruthlessly weeded out whenever possible so that the core of essential material is salient to the learner. Alternatively, cues should be included to direct the learner's cognitive processing of the essential material. In keeping with the coherence and redundancy principles, the amount and detail of information presented should be minimized, whereas in accordance with the signaling and spatial contiguity principles, the learner's attention should be directed toward the essential material. In keeping with the coherence principle, multimedia messages should not include words, pictures, and sounds that are not directly relevant to the goal of instruction. In keeping with the signaling principle, the multimedia message should contain cues that emphasize the core essential material, such as an outline and headings. In keeping with the redundancy principle, when a multimedia message consists of animation (or illustrations) and narration, it is important to avoid the temptation to add redundant on-screen text that mirrors the narration. In keeping with the spatial contiguity principle, when a multimedia message consists of graphics and printed words, the printed words should be placed near the part of the graphic they refer to. When a multimedia message says, "See Figure 1," there is a good chance that the spatial contiguity principle has been violated. Finally, in keeping with the temporal contiguity principle, it is important to present corresponding animation and narration at the same time. 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, research is needed in which the principles are tested within ecologically valid environments. Some positive examples include

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research in secondary school classrooms (e.g., Mousavi, Low, & Sweller, 1995; Sweller, Chandler, Tierney, & Cooper, 1990) and in industrial and professional training programs (e.g., Chandler & Sweller, 1991; Issa et al., 2011, 2013; Kalyuga, Chandler, & Sweller, 1999, 2000). Concerning the dependent measures, given that the goal of the five methods presented in this chapter is to reduce cognitive load, it would be useful to include direct measures of cognitive load in future research (Brünken, Plass, & Leutner, 2003; DeLeeuw & Mayer, 2008; Paas, Tuovinen, Tabbers, & van Gerven, 2003; Plass, Moreno, & Brünken, 2010).

Further research work is also needed so that we can better understand the conditions under which each of the principles is most effective. Concerning the coherence principle, minimizing detail in graphics and verbal explanations may be a good approach for novices, but more experienced learners may require a greater amount of detail. For example, according to the expertise reversal effect (described in Chapter 24) techniques that are helpful for novices may have the opposite effect for experts. Research is needed to calibrate the amount of detail that is appropriate for learners with different levels of prior knowledge.

Concerning the signaling principle, the results reported in this chapter are promising, but much more work is needed to determine the strength and robustness of verbal and visual forms of signaling. Although signaling has been found to improve learning from printed text (Loman & Mayer, 1983; Lorch, 1989), further research is needed to determine if signaling has the same effects in a multimedia environment, and particularly which kinds of visual cues are most effective.

Concerning redundancy, there may be situations in which presenting redundant spoken and printed words is warranted. For example, redundant multimedia messages may be more effective for special populations such as non-native speakers of a language or learners with hearing disabilities. Redundant multimedia messages may be more effective when the verbal material includes technical terms. Finally, when there are no graphics, redundant spoken and printed words can boost learning (Moreno & Mayer, 2002a), so additional research is needed concerning the conditions under which redundancy is helpful.

Concerning spatial contiguity, most of the studies have involved a small amount of material, such as a few pages. An important issue is whether it makes sense to revamp textbooks so that the layout of each page is designed to integrate words and graphics. Similar issues concern the design of online e-courses and the design of PowerPoint slides. Thus, there is a need for research that broadens the learning context beyond a few pages of integrated text and pictures.

Concerning temporal contiguity, it would be useful to determine the temporal limits of the principle. For example, do the words and pictures

have to be presented at exactly the same time, or can they be separated by a few seconds? On the basis of research by Baggett and Ehrenfeucht (1983) and Baggett (1984), it appears that learners experience difficulty even when corresponding words and pictures are separated by a few seconds. Further research is needed to determine the timing limitations for coordinating narration and animation in multimedia messages.

Glossary

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

Coherence principle: People learn more deeply from a multimedia message when extraneous material is excluded rather than included.

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

Essential processing: Cognitive processing – such as selecting relevant words and images, organizing selected words and images, and integrating – required to make sense out of the essential material; similar to Sweller's (1999) intrinsic cognitive load.

Extraneous material: Words and pictures that are not relevant to achieving the instructional objective, such as interesting stories or pictures.

Extraneous overload: What results when the amount of cognitive processing required by the essential and extraneous material in a multimedia instructional message exceeds the learner's cognitive capacity.

Extraneous processing: Cognitive processing that does not support the instructional goal and may occur when an instructional message contains too much detail, embellishment, or gratuitous information or when the layout of the material requires frequent switching of attention; similar to Sweller's (1999) extraneous cognitive load.

Redundancy principle: People learn more deeply from graphics and narration than from graphics, narration, and on-screen text.

Representational holding: Holding a representation of words or images in working memory.

Signaling principle: People learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material.

Spatial contiguity principle: People learn more deeply from a multimedia message when corresponding words and pictures are presented near rather than far from each other on the page or screen.

Temporal contiguity principle: People learn more deeply from a multimedia message when corresponding animation and narration are presented simultaneously rather than successively.

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