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## **Chapter 8 : Information-Processing Theory (pp. 166-0)**

### **Information-Processing Theory: Chapter Objectives**

#### **LEARNING OBJECTIVES**

After studying this chapter, you will be able to ...

**LO1** Explain what is meant by the information-processing view of learning.

**LO2** Describe the various components and processes that make up the multistore model of information processing.

**LO3** Define metacognition and explain how it affects the learning process.

**LO4** Describe the ways technology can help students improve how much and how well they learn different subjects.

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### **Information-Processing Theory: Chapter Overview**

*Learning*



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In Chapter 7 we noted that operant conditioning emphasizes the role of external factors in learning. Behavioral psychologists focus on the nature of a stimulus to which a student is exposed, the response that the student makes, and the consequences that follow the response. They see no reason to speculate about what takes place in the student's mind before and after the response. The extensive Suggestions for Teaching presented in Chapter 7 serve as evidence that conclusions and principles based on analyses of external stimuli, observable responses, and observable consequences can be of considerable value to teachers.

But cognitive psychologists, meaning those who study how the mind works and influences behavior, are convinced that it is possible to study nonobservable behavior, such as thought processes, in a scientific manner. Some of these cognitive psychologists are especially interested in an area of study known as *information-processing theory*, which seeks to understand how people acquire new information, how they create and store mental representations of information, how they recall it from memory, and how what they already know guides and determines what and how they will learn.

Before getting into the nuts and bolts of information-processing theory, we need to repeat the same caveat that we mentioned in Chapter 1: Don't look for explanations of how people encode, store, and retrieve information from memory that can be applied to all types of people, tasks, and settings. For all of its sophistication, research on memory has not progressed to the point where general laws can be formulated (Roediger, 2008). The interactions between people and the settings in which they function are too numerous and complex to allow for that kind of predictability. Once again, you will have to slip into the role of teacher-artist and figure out how to apply these insights to a given group of students, studying a particular part of the curriculum, who will be given a particular type of test to assess what they have learned.

### LO1 The Information-Processing View of Learning

Information-processing psychologists assume three things about how people learn: Information is processed in stages, there are limits on how much information can be processed at any stage, and previously learned information affects how and what people currently learn (Dehn, 2008; Linnell, 2007). Because learning is seen as the result of an interaction between the information to be learned and a learner who processes that information on the basis of existing knowledge schemes, this is a *constructivist* view of learning (Ashcraft & Radvansky, 2010; Winne, 2001). If you're not sure what a constructivist theory is, no need to worry; we give you a full explanation in Chapter 10.

A careful reading of this chapter is important because the information-processing decisions you make affect when you learn, how much you learn, how well you learn—indeed, whether you learn at all. To give you an appreciation of the information-processing approach to learning and how it can help teachers and students do their jobs, the next section will describe several basic cognitive processes and their role in the storage and retrieval of information.

Information processing: how humans attend to, recognize, transform, store, and retrieve information

## LO2 A Model of Information Processing

Many psychologists think of information as being held in and transferred among three memory stores: a sensory register, a short-term store, and a long-term store. Each store varies as to what processes are required to move information into and out of it, how much information it can hold, and how long it can hold information. A symbolic representation of these memory stores and their associated processes appears in Figure 8.1; called a *multistore* model, it is based on the work of several theorists (for example, Atkinson & Shiffrin, 1968; Norman & Rumelhart, 1970). Note that our use of the term *memory stores* is not meant to suggest specific locations in the brain where information is held; it is simply a metaphorical device for classifying different memory phenomena.



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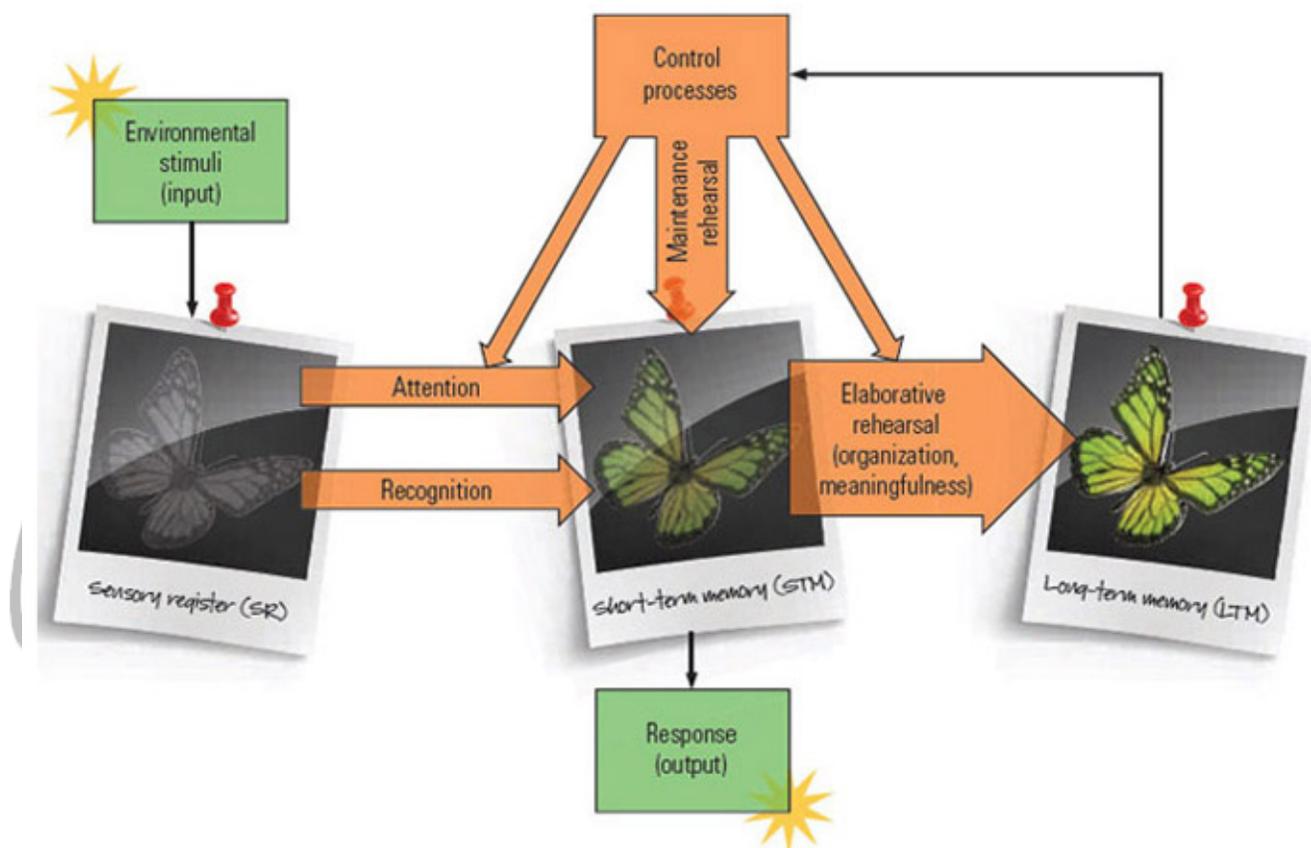
### Pause & Reflect

Can you think of any personal experiences that illustrate one or more of the three memory stores? Have you recently, for instance, retrieved a long-dormant memory because of a chance encounter with an associated word, sound, or smell?

As shown in Figure 8.1, control processes govern both the manner in which information is encoded and its flow between memory stores. These processes include recognition, attention, maintenance rehearsal, elaborative rehearsal (also called elaborative encoding), and retrieval. Each control process is associated primarily with a particular memory store.

The control processes are an important aspect of the information-processing system for two reasons. First, they determine the quantity and quality of information that the learner stores in and retrieves from memory. Second, it is the learner who

decides whether, when, and how to employ them. That the control processes are under our direct, conscious control will take on added importance when we discuss educational applications a bit later. Before we get to applications, however, we need to make you more familiar with the three memory stores and the control processes specifically associated with each of them.



**Figure 8.1 A Model of Information Processing** © Proxymo/Shutterstock © Ambient Ideas/Shutterstock Images

## The Sensory Register and Its Control Processes

### The Sensory Register

A description of how human learners process information typically begins with environmental stimuli. Our sense receptors are constantly stimulated by various sights, sounds, textures, odors, and tastes. These experiences are initially recorded in the *sensory register (SR)*, the first memory store. It is called the sensory register because the information it stores is thought to be encoded in the same form in which it is originally perceived—that is, as raw sensory data.

The purpose of the SR is to hold information just long enough (about 1 to 3 seconds) for us to decide whether we want to attend to it further. Information not selectively attended to and recognized decays or disappears from the system. At the moment you are reading these words, for example, you are being exposed to the appearance of letters printed on paper, sounds in the place where you are reading, and many other stimuli. The sensory register might be compared to an unending series of instant camera snapshots or video segments, each lasting from 1 to 3 seconds before fading away. If you recognize and attend to one of the snapshots, it will be “processed” and transferred to short-term memory.

### The Nature of Recognition

The process of *recognition* involves noting key features of a stimulus and relating them to already stored information. This process is interactive in that it depends partly on information extracted from the stimulus itself and partly on information stored in long-term memory. The ability to recognize a dog, for example, involves noticing those physical features of the animal that give it “dogness” (for example, height, length, number of feet, type of coat) and combining the results of that analysis with relevant information from long-term memory (such as that dogs are household pets, are walked on a leash by their owners, and are used to guard property).

To the degree that an object's defining features are ambiguous (as when one observes an unfamiliar breed of dog from a great distance) or that a learner lacks relevant prior knowledge (as many young children do), recognition and more meaningful processing will suffer. Recognition of words and sentences during reading, for example, can be aided by such

factors as clear printing and knowledge of spelling patterns, letter sounds, and the frequency with which words appear in natural language. The important point to remember is that recognition and meaningful processing of information are most effective when we make use of all available sources of information (Ashcraft & Radvansky, 2010; Leacock & Nesbit, 2007).

One implication of this information-processing view is that elementary school students need more structured learning tasks than middle school or high school students. Because of their limited store of knowledge in long-term memory and narrow ability to relate what they do know logically to the task at hand, younger students should be provided with clear, complete, explicit directions and learning materials (Doyle, 1983; Palmer & Wehmeyer, 2003).



Dog © Michael Pettigrew/Shutterstock Images;



Dog??? © artemisphoto/Shutterstock Images

### The Impact of Attention

The environment usually provides us with more information than we can deal with at one time. From the multitude of sights, sounds, smells, and other stimuli impinging on us at a given moment, we notice and record in the sensory register only a fraction. At this point, yet another reduction typically occurs. We may process only one third of the already-selected information recorded in the SR. We continually focus on one thing at the expense of something else. This selective focusing on a portion of the information currently stored in the sensory register is what we call **attention**.

Information in long-term memory influences what we attend to.

What governs what we attend to? According to one of the pioneers of cognitive psychology, Ulric Neisser, “Perceivers pick up only what they have schemata for, and willy-nilly ignore the rest” (1976, p. 79). In other words, we choose what we will see (or hear) by using our prior knowledge and experiences to anticipate the nature of incoming information. Students daydream, doodle, and write text messages rather than listen to a lecture because they anticipate hearing little of value.

Now, you may believe that you're more aware of what is going on around you than most other people. And you may be, but we doubt it. So what makes us think that your ability to attend to several things at once is probably no better than average? The results of the following experiment, which was conducted on college students much like you. If you were one of the subjects in this study (Chabris & Simons, 2010), you would be asked to watch a brief video of three people in white shirts passing a basketball to one another and three people in black shirts doing the same thing. Your task is to count how often the ball gets passed among the three participants in white shirts and ignore how often the three people in the black shirts pass the ball to one another. Not a particularly hard task, but it does require you to focus your attention on the people in the white shirts. At some point during this ball-passing activity, another person, dressed in a gorilla suit, walks into the scene, stops, faces the camera, beats on his chest, turns, and walks out of the other side of the scene. The gorilla is visible for 9 seconds.

After viewing the video, the experimenter then asks you to report what you saw. You're probably thinking that the first words out of your mouth would be something like, "You probably won't believe me, but I saw a gorilla!" We hate to disappoint you, but since half the subjects in this study said they didn't "see" a gorilla, you probably wouldn't have either. We put "see" in quotation marks because the gorilla did fall within each subject's field of vision. We know this because the researchers also tracked their eye movements, and knew whether an image of the gorilla appeared on each person's retina. This phenomenon is called *inattention blindness* and explains why people who text and drive or talk on a cell phone while driving are more likely to have an accident than people who focus entirely on their driving. If you're meaningfully processing a phone conversation, you're not attending to and processing the conditions on the road.



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## Short-Term Memory and Its Control Processes

### Short-Term Memory

Once information has been attended to, it is transferred to *short-term memory (STM)*, the second memory store. Short-term memory can hold anywhere from five to nine (seven is the average) unrelated bits of information for approximately 20 seconds. Although the capacity of STM is relatively small, we can expand this limit a bit by using a technique called *chunking*, which we describe in this chapter's Suggestions for Teaching. The brief amount of time that information remains available in STM may seem surprising, but it can be easily demonstrated. Imagine that you look up and dial an unfamiliar phone number and receive a busy signal. If something or someone else then distracts you for 15 to 20 seconds,

chances are you will have forgotten the number.

Short-term memory is more than just a place to temporarily store whatever we are currently thinking about (ideally, this page of the textbook rather than last night's party). It is also where we encode, organize, and retrieve information. Psychologists use the term *working memory* to refer to the aspect of STM that actively processes information. So when we try to figure out how to compose a sentence, solve a math problem, or recall a scientific formula, those activities take place in working memory.

Working memory is increasingly being viewed as a critical component in our information-processing system (Klingberg, 2009; Rose, Myerson, Roediger, & Hale, 2010; Thorn & Page, 2009). Logic suggests, and research has confirmed, that differences in working memory are strongly related to differences in such basic skills as reading comprehension, listening comprehension, oral expression, writing, math calculation, and math reasoning (Dehn, 2008). Preschool and first grade children, for example, who scored higher than their peers on a test of working memory were better able to complete a card sorting task that required keeping track of several pieces of information (Marcovitch, Boseovski, Knapp, & Kane, 2010). This finding does not, however, mean that students with a smaller working memory are doomed to be underperformers. The same researchers cited evidence that children can be trained to use their working memory more effectively.

## Rehearsal

A severe limitation of short-term memory is how quickly information disappears or is forgotten in the absence of further processing. This problem can be dealt with through *rehearsal*. Most people think of rehearsal as repeating something over and over either in silence or out loud. The usual purpose for such behavior is to memorize information for later use, although occasionally we simply want to hold material in short-term memory for immediate use (for example, to redial a phone number after getting a busy signal). Rehearsal can serve both purposes, but not in the same way. Accordingly, cognitive psychologists have found it necessary and useful to distinguish two types of rehearsal: maintenance and elaborative.

**Maintenance rehearsal** (also called *rote rehearsal* or *repetition*) has a mechanical quality. Its only purpose is to use mental and verbal repetition to hold information in short-term memory for some immediate

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purpose. Although this is a useful and often-used capability (as in the telephone example), it has no effect on long-term memory storage.

**Elaborative rehearsal** (also called *elaborative encoding*) consciously relates new information to knowledge already stored in long-term memory. Elaboration occurs when we use information stored in long-term memory to add details to new information, clarify the meaning of a new idea, make inferences, construct visual images, and create analogies (Dunlosky & Bjork, 2008a). In these ways, we facilitate both the transfer of information to long-term memory and its maintenance in short-term memory. For example, if you wanted to learn the lines for a part in a play, you might try to relate the dialogue and behavior of your character to similar personal experiences you remember. As you strive to memorize the lines and actions, your mental "elaborations" will help you store your part in long-term memory so that you can retrieve it later. Our Case in Print for this chapter illustrates how people can memorize what seem to be impossibly large amounts of information through the skilled use of elaborative encoding.

Elaborative rehearsal, whereby information from long-term memory is used in learning new information, is the rule rather than the exception. Mature learners don't often employ maintenance rehearsal by itself. The decision to use one or the other, however, depends on the demands you expect the environment to make

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on you. If you need to remember things for future use, use elaborative rehearsal; if you want to keep something in consciousness just for the moment, use rote rehearsal.

So far, we have explained the effect of elaborative rehearsal in terms of relating new information to information already stored in long-term memory. That's fine as a very general explanation. But to be more precise, we need to point out that elaborative rehearsal is based on *organization* (for example, grouping several items together on some common basis and rehearsing them as a set) and *meaningfulness* (relating the lines in a play to similar personal experiences, for example).

Organizing material reduces the number of chunks and provides recall cues.

## Organization

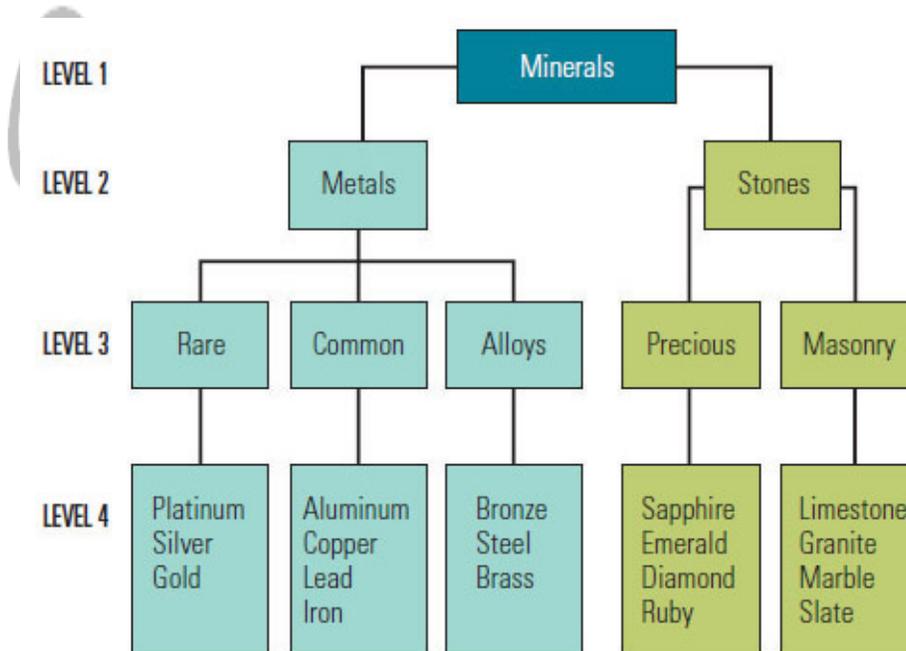
Quite often the information we want to learn is complex and interrelated. We can make this type of material easier to learn

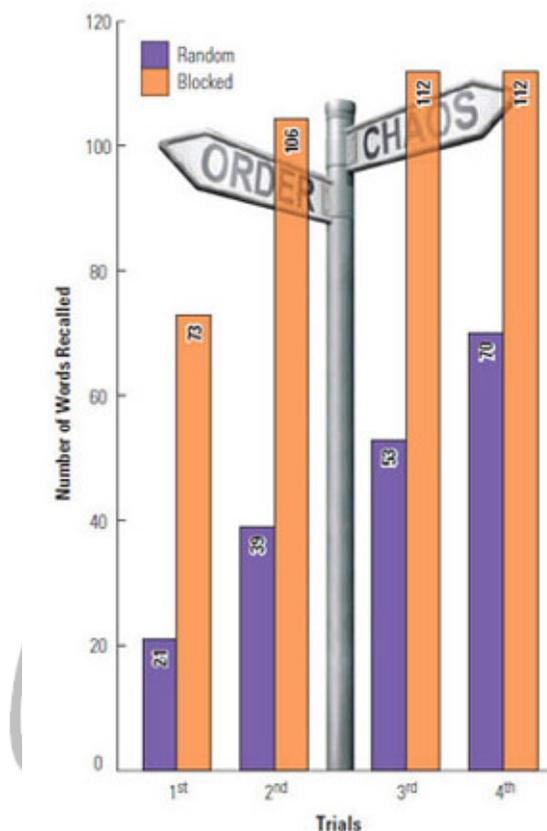
by organizing multiple pieces of information into a few “clumps,” or “chunks,” of information, particularly when each part of a chunk helps us remember other parts (Cowan, 2005). The value of organizing material was illustrated by a classic experiment (Bower, Clark, Lesgold, & Winzenz, 1969) in which two groups of participants were asked to learn 112 words in four successive lists but under different conditions. One group was given each of the four lists for four trials in the hierarchical or “blocked” arrangement displayed in Figure 8.2. The other group was given the same lists and the same hierarchical tree arrangement, but the words from each list were randomly arranged over the four levels of the hierarchy.

As you can see, through the first three trials, the group given the word lists in a blocked arrangement recalled more than twice as many words as the group given the words in a random arrangement and achieved perfect recall scores for the last two trials. The organized material was much easier to learn not only because there were fewer chunks to memorize but also because each item in a group served as a cue for the other items. When you decide to store pertinent material from this chapter in your long-term memory in preparation for an exam, you will find the job much easier if you organize what you are studying.

### Meaningfulness

The meaningfulness of new information that a person is about to learn has been characterized as “potentially the most powerful variable for explaining the learning of complex verbal discourse” (R. E. Johnson, 1975, pp. 425–426). According to David Ausubel (Ausubel, Novak, & Hanesian, 1978), *meaningful learning* occurs when a learner encounters clear,





**Figure 8.2 Hierarchical Arrangement of Words Produces Superior Recall** Bower, Clark, Lesgold, & Winzenc (1969). Photo: © Dirk Ercken/Shutterstock Images

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logically organized material and consciously tries to relate the new material to ideas and experiences stored in long-term memory. To understand learning theory principles, for example, you might imagine yourself using them to teach a lesson to a group of students. Or you might modify a previously constructed flowchart on the basis of new information. The basic idea behind meaningful learning is that the learner actively attempts to associate new ideas with existing ones (Loyens & Rikers, 2011; Thorn & Page, 2009). As another example, many of the Pause & Reflect questions in this book are designed to foster meaningful encoding by getting you to relate text information to relevant prior experience. As you will see in Chapter 10, instructional approaches that are based on the principle of meaningfulness emphasize such active forms of learning as doing projects and solving problems that relate to students' everyday lives (as well as to state standards).

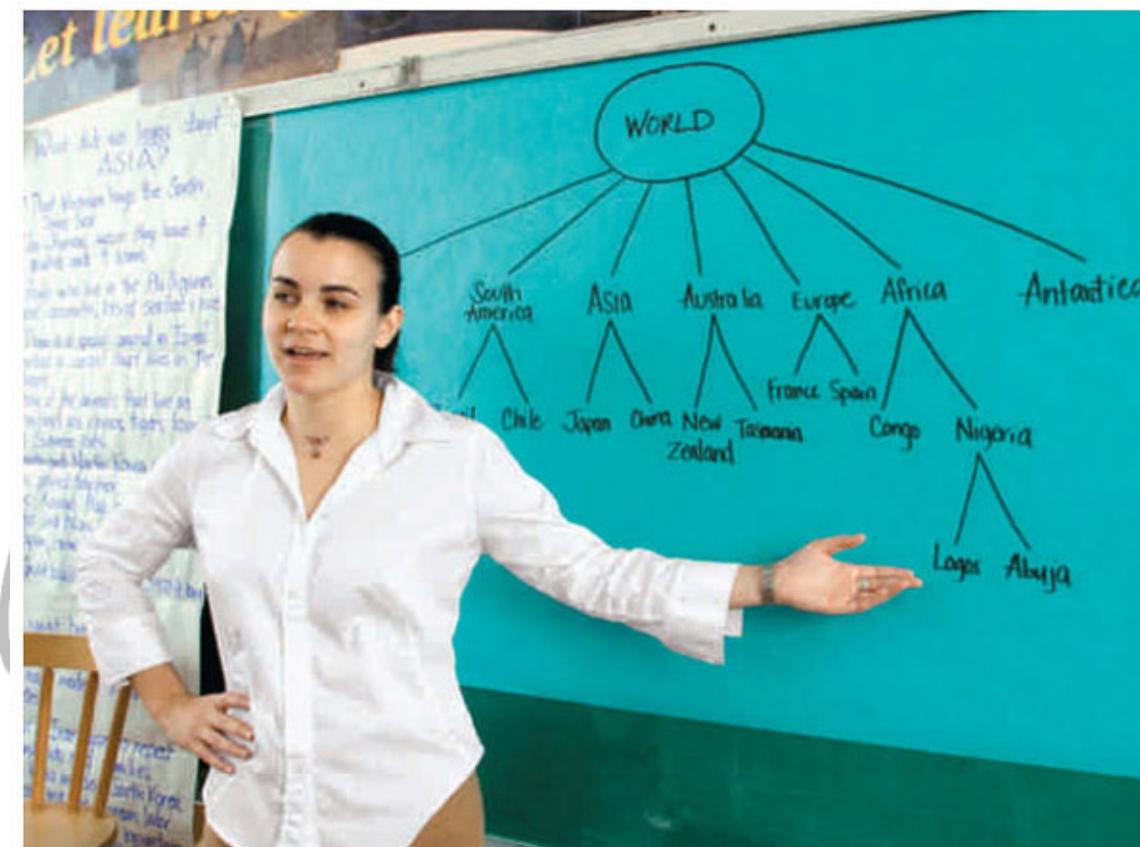
Meaningful learning occurs when organized material is associated with stored knowledge.

This brief description of meaningfulness and its role in learning contains a strong implication for teaching in culturally diverse classrooms: You can foster meaningful learning for students from other cultures by pointing out similarities between ideas presented in class and students' culture-specific knowledge. For example, you might point out that September 16 has the same significance to the people of Mexico as July 4 has to U.S. citizens because the former date commemorates Mexico's revolution against and independence from Spain.

### Visual Imagery Encoding

Like pictures, images can be said to be worth a thousand words because they contain a wealth of information in a compact, organized, and meaningful format. Consider Benjamin Banneker (1731–1806), who has been called the first Black intellectual. Banneker was a self-taught mathematician, astronomer, and surveyor (Cothran, 2006). He predicted a solar eclipse in 1789, published tide tables, and was appointed by President George Washington to the commission that established the boundaries of Washington, DC. His accomplishments (such as building a wooden clock based just on an earlier examination of the workings of a pocket watch) suggest that mental imagery was critical to his thinking. Other

notable individuals, such as Albert Einstein (physics), Michael Faraday (physics), James D. Watson (biochemistry), and Joan Didion (literature) have described how mental imagery played a significant role in their thinking and problem-solving efforts (Shepard, 1978).



**To help students encode information, teach them how to group objects and ideas according to some shared feature.** © Michael Newman/Photo Edit

Research has consistently shown that students who are directed to generate visual images as they read lists of words or sentences, several paragraphs of text, or lengthy text passages attain higher levels of comprehension and recall than students who are not so instructed. Also, text passages that contained many concrete words and phrases were more easily



**Meaningful learning occurs when a learner relates, either spontaneously or with help, clearly written and logically organized information to existing networks of information stored in long-term memory.** Jim Cummins/Taxi/Getty Images

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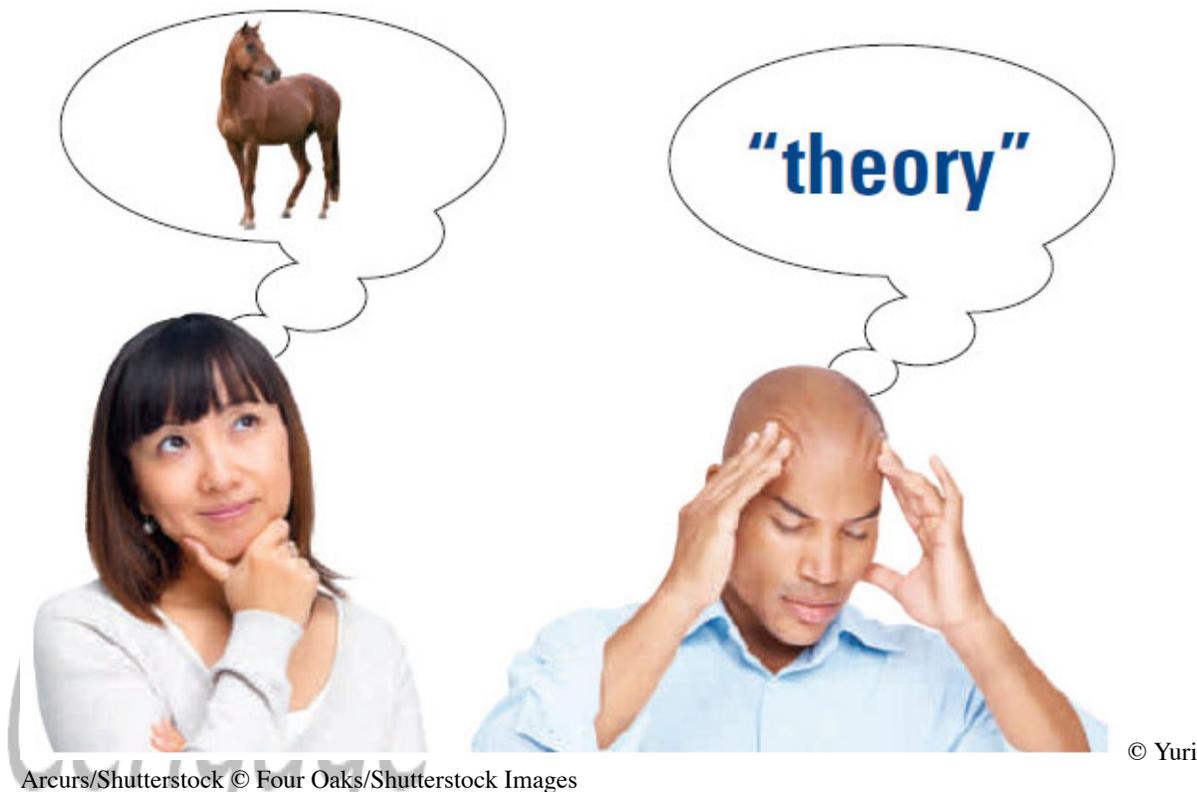
understood and more accurately recalled than passages that contained more abstract than concrete ideas (J. M. Clark & Paivio, 1991). In one study (Sadoski, Goetz, & Rodriguez, 2000), the beneficial effect of concreteness was obtained for several passage types (such as expository text, persuasive text, stories, and narratives). The more concrete the passage was, the more it was rated comprehensible by students, and students who read concrete passages recalled 1.7 times as much information as students who read abstract passages. As we will see in the next chapter, concreteness and visual imagery are an integral part of several effective study skills.

The theory that these findings support is Allan Paivio's dual coding theory (Clark & Paivio, 1991; Meilinger, Knauff, & Bülthoff, 2008; Sadoski & Paivio, 2007). According to the *dual coding theory*, concrete material (such as pictures of familiar objects) and concrete words (such as *horse*, *bottle*, and *water*) are remembered better than abstract words (such as *deduction*, *justice*, and *theory*) because the former can be encoded in two ways—as images and as verbal labels—whereas the latter are encoded only verbally. This makes retrieval easier because a twice-coded item provides more potential retrieval cues than an item that exists in only one form.

Before you go on to read about long-term memory, look at Table 8.1, which summarizes some important points about the control processes of short-term memory and the implications for teachers. Later in the chapter, the Suggestions for Teaching will help you put these ideas into practice.

## **Long-Term Memory**

We have already referred in a general way to the third memory store, *long-term memory (LTM)*, which is perhaps the most interesting of all. On the basis of



neurological and experimental, evidence, most cognitive psychologists believe that the storage capacity of LTM is unlimited and that it contains a permanent record of everything an individual has learned, although some doubt exists about the latter point (see, for example, W. A. Rogers, Pak, & Fisk, 2007; Schunk, 2004).

The neurological evidence comes from the work of Wilder Penfield (1969), a Canadian neurosurgeon who operated on more than 1,000 patients who experienced epileptic seizures. To determine the source of the seizures, Penfield electrically stimulated various parts of the brain's surface. During this procedure, many patients reported vivid images of long-dormant events from their past. It was as if a neurological video had been turned on.

The experimental evidence, although less dramatic, is just as interesting, and it too has its origins in the early days of information-processing theory. In a typical memory study (such as Tulving & Pearlstone, 1966), participants receive a list of nouns to learn. After giving them ample opportunity to recall as many of the words as possible, researchers provide retrieval cues—for instance, category labels such as “clothing,” “food,” or “animals.” In many cases, participants who are given the cues quickly recall additional items. Experiments on how well people recognize previously seen pictures have produced some startling findings. Thirty-six hours after viewing more than 2,500 pictures, a group of college students correctly identified an average of about 2,250, or 90% (Standing, Conezio, & Haber, 1970).

Before we move on to a discussion of how information is organized in long-term memory, let's make sure we understand what the research mentioned in the previous two paragraphs does and does not imply. It does suggest that there is more information in long-term memory than we can get to on a given occasion. How many of you have had the experience of not being able to recall a piece of information that you knew was in long-term memory, only to be able to recall it some time later? What this research does not suggest, however, is that everything we have ever experienced is stored there in something like a photographic or videographic record. As you now know, information that is not noticed or linked with previously learned information never gets beyond the short-term store. What you will learn shortly is that quite a bit of what is stored in long-term memory is different from when it was first learned. In other words, we often operate on the basis of distorted knowledge. Read on to find out why.

### How Information Is Organized in Long-Term Memory

As you have seen, long-term memory plays an influential role throughout the information-processing system. The interests, attitudes,

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<b>Table 8.1 Implications for Instruction: How Findings About the Control Processes of Short-Term Memory Should</b>
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<b>Influence Your Teaching</b>	
<b>Research Finding</b>	<b>Implications</b>
<i>Recognition</i> involves relating a stimulus to information from long-term memory.	Compared with older students, elementary school students have less knowledge stored in long-term memory, and therefore they need structured learning tasks in which one step leads clearly to the next.
<i>Attention</i> is influenced by previous experience stored in long-term memory—we notice what we expect to be important.	Teachers should develop techniques for capturing students' attention and convincing them that the information being presented will be important to them.
<i>Rehearsal</i> prevents the quick disappearance of information from short-term memory. Most children do not begin to rehearse on their own until about age seven.	All children, especially younger ones, can benefit from being taught rehearsal techniques.
<i>Organization</i> of material into chunks makes it much easier to remember.	Teachers can aid students by presenting material in logical chunks and by showing students how to organize information on their own.
<i>Meaningful learning</i> occurs when the learner relates new information to prior ideas and experiences.	Teachers should mediate learning by relating new information to students' cultural knowledge and by helping students to learn techniques of self-mediation.
<i>Visual imagery</i> is easier to recall than abstractions.	Teachers should help students develop learning skills that incorporate visual imagery and other memory-aiding techniques.

**Table 8.1 Implications for Instruction: How Findings About the Control Processes of Short-Term Memory Should Influence Your Teaching**

skills, and knowledge of the world that reside there influence what we perceive, how we interpret our perceptions, and whether we process information for short-term or long-term storage. In most instances, retrieval of information from long-term memory is extremely rapid and accurate, like finding a book in a well-run library. Accordingly, we can conclude that information in long-term memory must be organized. The nature of this organization is a key area in the study of memory. The insights it provides help to illuminate the encoding and retrieval processes associated with long-term memory.

Information in long-term memory is organized as schemata.

Many cognitive psychologists believe that our store of knowledge in long-term memory is organized in terms of *schemata* (which is the plural of *schema* and is related in meaning to Jean Piaget's *scheme*). A schema is typically defined as an abstract structure of information. It is abstract because it summarizes information about many different cases or examples of something, and it is structured because it represents how its own informational components are interrelated. Schemata give us expectations about objects and events (dogs bark, birds fly, students listen to their teachers and study industriously). When our schemata are well formed and a specific event is consistent with our expectation, comprehension occurs. When schemata are poorly structured or absent, learning is slow and uncertain (Bruning, Schraw, Norby, & Ronning, 2004; Lewandowsky & Thomas 2009; Moreno, 2006; Schunk, 2004).

The effect of schemas on memory and comprehension was first investigated during the early 1930s by Sir Frederic Bartlett (1932), an English psychologist. In one experiment, Bartlett had participants read and recall a brief story, titled "The War of the Ghosts," that was based on North American Indian folklore. Because Bartlett's participants had little knowledge of American Indian culture, they had difficulty accurately recalling the story; they omitted certain details and distorted others. The distortions were particularly interesting because they



**Because people interpret new information and experiences on the basis of existing memory schemes, and because no two people's schemes are identical, each person is likely to represent the same idea or experience in a unique fashion.** © Jeff Greenberg/Photo Edit

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reflected an attempt to interpret the story in terms of the logic and beliefs of Western culture. Similar studies, conducted more recently with other kinds of reading materials, reported similar results (Derry, 1996; T. L. Griffiths, Steyvers, & Tenenbaum, 2007). The conclusion that Bartlett and other researchers have drawn is that remembering is not simply a matter of retrieving a true-to-life record of information. People often remember their *interpretations* or *constructions* of something read, seen, or heard (Lampinen & Odegard, 2006). In addition, when they experience crucial gaps in memory, they tend to fill in these blanks with logical reconstructions of what they think must have been. People then report these reconstructions as memories of actual events (Derry, 1996).

### Why We Forget

Forgetting is a fact of life. We all do it and will continue to do it for as long as we live. But before we get into the possible reasons why forgetting occurs, we need to clarify exactly what we mean by the term. Forgetting is the inability, often temporary but possibly permanent, to retrieve *previously learned information*. That deliberate choice of wording eliminates from consideration a very common experience that is often referred to as forgetting by the average person: failing to recall something that was never learned in the first place. If a student complains that she can't recall what the teacher said in class, it may be because she was busy checking her e-mail or Facebook page. This is an attention and motivation problem, not a forgetting problem (Wixted, 2010).

So if experimental, neurological, and clinical evidence suggest that long-term memory is a limitless, permanent, and organized storehouse of previously learned information, then why do we sometimes have difficulty getting at that information when we want it? If you're looking for one simple answer, sorry, you've come to the wrong place. There are several possible reasons why forgetting occurs (see Roediger, Weinstein, & Agarwal, 2020). Which explanation best explains a failed recall attempt will depend on the circumstances.



**cheveux or cheval?** © Four Oaks/Shutterstock Images

### **Inadequate Consolidation**

Sometimes forgetting occurs because the material wasn't adequately learned in the first place. When learning new material, many students will try to learn as much of it as possible in as little time as possible. Students call this *cramming*. Psychologists call it *massed practice*. Whatever the label, it's a terrible tactic because it typically produces a disorganized and poor-quality representation in LTM that is hard to retrieve. A better option is to engage in *distributed practice*: Study and then reread smaller chunks of material at regular intervals. This is thought to strengthen the representation of the material in memory and to distinguish it from material learned later, a process memory researchers call *consolidation*. We discuss massed and distributed practice in more detail in the Suggestions for Teaching on pages 178 and 179.

### **Nonmeaningful Learning**

A second reason why forgetting occurs is that the information is so different from anything we already know that we can't connect it to existing knowledge schemes in a meaningful way. Recall of this information is marked by omissions and distortions. A good example of how nonmeaningful material negatively affects retrieval from LTM is our discussion in the previous section of Bartlett's research with the "War of the Ghosts" passage. We suggest ways to deal with this problem in the Suggestions for Teaching in this chapter and the next.

### **Few Opportunities for Retrieval**

Our third reason is one you probably don't want to hear: You don't take enough tests as you are learning new material! Yes, we know you don't like tests, but that's because they usually have high stakes attached to them (they're used to determine your grade). But tests (short quizzes, actually) can also be used to give you feedback about how well you are learning and, by stimulating you to recall what you learned, strengthen those representations in LTM.

### **Interference From Other Material**

Being a student means having to cope with a constant stream of learning material. Inevitably, we encounter ideas that are similar to those we learned earlier but call for different responses. In such cases, interference from material learned earlier, whether in school or out, can make it difficult to come up with the correct response. This happens quite frequently in learning a foreign language because words that look alike mean different things. Take, for example, the French words for hair (*cheveux*) and horse (*cheval*). Students frequently make the wrong choice because of the similarity in spelling and pronunciation. Another example is when a teacher tries to learn the names of a new group of students at the beginning of the year and calls some of them, at least for a while, by the names of the students in the previous class.

## Lack of Retrieval Cues

Our last explanation concerns the availability of retrieval cues. A retrieval cue can be any information, such as a word, phrase, image, sound, and so on, that is associated with the learned material. Learning does not take place in a vacuum; it occurs in a specific context that includes aspects of the

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physical environment, characteristics of the learning material, and associated thoughts. Let's say that as you read this chapter you also take note of the headings and subheadings and create analogies (like thinking of short-term memory as a funnel that's seven chunks wide). If that additional information is present when you want to recall the chapter's content, either because it's given to you or because you can generate it yourself, you're more likely to recall the target information. This is known as the *encoding specificity principle*: Retrieval is more likely to be successful when material that was part of the original encoding is present at the time of recall. The power of retrieval cues is such that one researcher said, "If the right retrieval cue does not come along, the corresponding memory trace might as well not even be there as it will never be retrieved again" (Wixted, 2010, p. 287).

The previous several sections vividly demonstrate the interactive nature of memory. What we know influences what we perceive and how we interpret and store those perceptions. And because our memories of specific events or experiences are assembled, constructed, and sometimes reassembled by the brain over time, accurate and complete recall of information we once stored is not always possible. As a teacher, then, you should pay deliberate attention to how your students use their background knowledge, helping them to use it as accurately and completely as possible to process new information.

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## TeachSource Video Case: Cooperative Learning in the Elementary Grades: Jigsaw Model



Go to the Education CourseMate website and watch the video, study the artifacts in the case, and reflect upon the following questions:

1. How do the students in this Video Case demonstrate the information-processing concepts of attention and elaborative rehearsal?
2. What are some ways that students in this Video Case demonstrate how their prior knowledge (information in long-term memory) influences their preparation in expert groups, their peer teaching to their home groups, and their assessments?



Cengage

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### Case in Print: A Head for Numbers

Elaborative rehearsal (also called *elaborative encoding*) consciously relates new information to knowledge already stored in long-term memory. Elaboration occurs when we use information stored in long-term memory to add details to new information, clarify the meaning of a new idea, make inferences, construct visual images, and create analogies (Dunlosky & Bjork, 2008a). In these ways, we facilitate both the transfer of information to long-term memory and its maintenance in short-term memory.

### A Small Number With a Big Following

DON TROOP

*Chronicle of Higher Education*, 3/7/10

At precisely 1:59 a.m. on Sunday, Joe Anderson will arise at his parents' home and begin reciting, by memory, the first thousand digits of pi: "3.14159265358979323846...."

Mr. Anderson has performed this exercise previously on Pi Day, an informal holiday that math lovers observe every March 14 in honor of their favorite irrational number: pi—so tiny (it's closer to three than four) yet random and infinite (as far as anyone knows).

Mr. Anderson, 17, is a student at the Texas Academy of Mathematics and Science, a two-year residential program at the University of North Texas that allows exceptional students to complete their freshman and sophomore years of college while earning the equivalent of a high-school diploma. His interest in the function of memory led him to take on the challenge of reciting pi. He visualizes the numbers in groups of five or 10 and practices by typing the digits into his calculator, which is programmed to tell him if he's made a mistake. When he performs his trick in front of an audience—it takes about 10 minutes, he says—he imagines punching the numbers into an invisible keypad.

"My plan for this year is to memorize the thousand I know, but learn them better," says Mr. Anderson, an aspiring physicist who will be on spring break this Pi Day. "I will memorize them while doing something with my hands so I can't utilize the muscle memory. I'm thinking of doing Chinese yo-yo tricks while I recite the numbers so I won't be able to type out imaginary keys with my hands."

Mr. Anderson's talent for remembering might seem superhuman, but his thousand-number feat is dwarfed by that of a Chinese graduate student, Lu Chao, who captured the world record in 2005 by reciting pi to 67,890 digits over 24 hours, according to PhysOrg. com. The world record for calculating pi is even more daunting. A computer scientist in France, Fabrice Bellard, recently carried out the value of pi to 2.7 trillion decimal points. Mr. Bellard, PhysOrg reports, ran his own software algorithms on a personal computer, completing his 131-day task on December 31, 2009.

Learning

When it comes to memorization, those of us who struggle to retain even the basic numbers of life—birthdays, anniversaries, ATM passcodes—would do well to use a popular mnemonic device, a sentence in which the letter counts of each word signify the first 15 numbers of pi: “How I want a drink, alcoholic of course, after the heavy lectures involving quantum mechanics!”

Source: Don Troop, “A small number with a big following,” from *Chronicle of Higher Education*, March 7, 2010. Copyright 2010, the *Chronicle of Higher Education*. Reprinted with permission.

### Questions and Activities

1. The elaborative encoding techniques used by Joe Anderson to memorize the first thousand digits of pi obviously account for a large part of his success in performing this task. But the article suggests other contributing factors. What might they be?
2. Given how effective elaborative encoding techniques are at helping us process information, why don't more people use them? Use yourself as a case study to answer this question.
3. Would you be willing to memorize a large amount of information as a way to demonstrate to your students how powerful elaborative encoding techniques are and to motivate them to emulate your feat?



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### LO3 Metacognition

The discussion up to this point has focused on how people attend to, encode, store, and retrieve information. In other words, we have described some basic cognitive processes. But there's another dimension to

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this story that you need to know about: a more general level of thinking that makes it possible for us to control memory and other cognitive processes. That level of thinking, which is called *metacognition*, refers to the ways that what we know about the nature of our own thought processes affects how we learn and solve problems.

### The Nature and Importance of Metacognition

The notion of metacognition was proposed by developmental psychologist John Flavell (1976) to explain why children of different ages deal with learning tasks in different ways. For example, when 7-year-olds are taught how to remember pairs of nouns using both a less effective technique (simply repeating the words) and a

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more effective technique (imagining the members of each pair doing something together), most of these children will use

the less effective technique when given a new set of pairs to learn. Most 10-year-olds, however, will opt to use the more effective method. The explanation for this finding is that the 7-year-old has not had enough learning experiences to recognize that some problem-solving methods are better than others. To the younger child, one means is as good as another. This lack of metacognitive knowledge makes true strategic learning impossible for young children (Ornstein, Grammer, & Coffman, 2010).

One way to grasp the essence of metacognition is to contrast it with cognition. The term *cognition* is used to describe

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the ways in which information is processed—that is, the ways it is attended to, recognized, encoded, stored in memory for various lengths of time, retrieved from storage, and used for one purpose or another. **Metacognition** refers to our knowledge about those operations and how they might best be used to achieve a learning goal. As Flavell put it:

I am engaging in metacognition ... if I notice that I am having more trouble learning A than B; if it strikes me that I should double-check C before accepting it as a fact; if it occurs to me that I had better scrutinize each and every alternative in any multiple-choice type task situation before deciding which is the best one; if I become aware that I am not sure what the experimenter really wants me to do; if I sense that I had better make a note of D because I may forget it; if I think to ask someone about E to see if I have it right. Such examples could be multiplied endlessly. (1976, p. 232)

Metacognition is obviously a very broad concept. It covers everything an individual can know that relates to how information is processed (see W. Schneider, 2010; Van Overschelde, 2008). To get a better grasp of this concept, you may find it helpful to think of metacognition as being made up of *declarative*, *conditional*, and *procedural* components.

Declarative knowledge can be thought of as “knowing that” and is composed of

- *Knowledge-of-person variables*: for example, knowing that you are good at learning verbal material but poor at learning mathematical material, or knowing that you quickly forget information that is not rehearsed or encoded.
- *Knowledge-of-task variables*: for instance, knowing that passages with long sentences and unfamiliar words are usually harder to understand than passages that are more simply written.
- *Knowledge-of-strategy variables*: for example, knowing that mnemonic devices (we describe these in the next chapter) make it easier to store and retrieve information from LTM in verbatim form, but that concept maps (also described in the next chapter) aid comprehension of a reading passage.

Conditional knowledge concerns knowing when and why we use certain learning processes in certain circumstances. Knowing that good readers first skim a reading passage to learn about its length and structure and to gain some familiarity with it, and that effective study requires a certain minimum amount of time with no distractions present are examples of conditional knowledge.



**Metacognition refers to the knowledge we have about how we learn. It is a key component of our ability to regulate our learning processes.** © VStock/Alamy

Procedural knowledge involves knowing how to use various cognitive processes. Examples include knowing how to skim a passage versus reading it for comprehension, knowing how to test one's comprehension of a passage, and knowing how to create effective concept maps.

### Age Trends in Metacognition

Because metacognitive knowledge develops gradually throughout childhood and adolescence, there are significant differences in what younger and older children know about their cognitive processes and how to control them. The following summary of research findings (see Duell, 1986; Larkin, 2010; W. Schneider, 2010; B. Schwartz, 2011; Waters & Kunmann, 2010) should give you some idea of what to expect with children of different ages:

- In terms of diagnosing task difficulty, most 6-year-olds know that more familiar items are easier to remember than less familiar items and that a small set of items is easier to recall than a large set of items. What 6-year-olds do not yet realize is that the amount of information they can recall immediately after they study it is limited.
- Similar findings have been obtained for reading tasks. Most second graders know that interest, familiarity, and story length influence comprehension and recall. However, they are relatively unaware of the effect of how ideas are sequenced,

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the introductory and summary qualities of first and last paragraphs, and the relationship between reading goals and tactics. Sixth graders, by contrast, are much more aware of the effects of these variables on comprehension and recall.

- Most young children know very little about the role their own capabilities play in learning. For example, not until about 9 years of age do most children realize that their recall right after they study something is limited. Consequently, children through the third grade usually overestimate how much they can store in and retrieve from short-term memory.
- Many kindergarten and first grade children try to remember a set of objects by using such techniques as naming them, grouping them in categories, arranging them in alphabetical order, or creating a story about them. But fewer of them can explain why these techniques work. Many fourth and fifth graders, however, do understand how these tactics aid recall.

- In terms of monitoring the progress of learning, most children younger than 7 or 8 are not very proficient at determining when they know something well enough to pass a memory test. Also, most first graders typically don't know what they don't know. When given multiple opportunities to study and recall a lengthy set of pictures, 6-year-olds chose to study pictures they had previously seen and recalled, as well as ones they hadn't. Third graders, by contrast, focused on previously unseen pictures.

Insight into one's learning processes improves with age.

The general conclusion that emerges from these findings is that the youngest school-age children have only limited knowledge of how their cognitive processes work and when to use them. Consequently, primary grade children do not systematically analyze learning tasks, formulate plans for learning, use appropriate techniques of enhancing memory and comprehension, or monitor their progress because they do not (some would say cannot) understand the benefits of doing these things. But as the two studies we are about to discuss indicate, even primary grade children are capable of using what they know under the right circumstances to enhance their learning and of benefiting, both immediately and years later, from metacognitive instruction and feedback.

In the first study (Waters & Kunnmann, 2010), first graders were asked to learn the names of eight pictured items and were told that pairs of items belonged to the same category (e.g., pants and hat are clothing, shovel and rake are tools). The children were then told to arrange the items in any way that would make it easier for them to recall later. Not only did they arrange most of the items in category pairs, but they were able to explain that they did so to make it easier for them to recall as many items as possible (on average, about 87%). Now here's the interesting part of this study: When these same children were given a set of 16 items (four per category), their performance and metacognitive awareness dropped off considerably. The classroom implication is that young children can be prompted to demonstrate metacognitive awareness, but only on tasks that are well within their working-memory capabilities.

The second study (Ornstein, Grammer, & Coffman, 2010) demonstrated the value of providing first graders with both memory instruction (“Remember to read out loud what you wrote to see if it makes sense”; “To help you remember which number is in the tens place, write a T above it, and to help you remember which number is in the ones place, write an O above it”) and metacognitive feedback (“Tell me how you solved that problem”; “Let me explain why labeling the place values of a number is a good way to remember them”). By the fourth grade, these same students were more likely to use such study skills as note taking, rereading, and self-testing than were students whose first grade teachers provided very little memory instruction and metacognitive feedback.

The main implication for classroom instruction that flows from the research on metacognition is that you can encourage your students to develop their metacognitive skills and knowledge by thinking about the various conditions that affect how they learn and remember. The very youngest students (through third grade) should be told periodically that such cognitive behaviors as describing, recalling, guessing, and understanding mean different things, produce different results, and vary in how well they fit a task's demands. For older elementary school and middle school students, explain the learning process and focus on the circumstances in which different learning tactics are likely to be useful. Then have students keep a diary or log in which they note when they use learning tactics, which ones, and with what success. Look for cases in which good performance corresponds to frequent reported use of tactics and positively reinforce those individuals. Encourage greater use of tactics among students whose performance and reported use of them are below average.

Next we examine several ways in which you can use computer-based technology to improve your students' information-processing skills for a variety of learning tasks.

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## **Challenging Assumptions: Students Are Learners, Not Just Performers**

Visit a school in the last 2 months of winter and you will see teachers preparing their students to perform as well as they possibly can on the state exams in April and May. Ask teachers why they are so focused on the state exams, and they will tell you that the administration has made student performance on the exams a top priority. Ask the administrators why student performance on the exams deserves so much time and energy, and they will tell you that poor student performance on the exams can decrease property values in the community, can mean the replacement—at considerable expense—of an entire curriculum, and can even cost teachers and administrators their jobs. As you will see in Chapter 15, a lot is riding on students' performance on the state exams. And so teachers guide students through the material they expect to be on the tests; teachers go over and over it in an effort to ensure that every student gets every possible test item correct. The teachers lead the students through seemingly endless drill and practice. (Some teachers—and some students—call it “drill and kill.”) The teachers work very hard, the students work very hard, and the administrators feel the pressure and keep the

pressure on.



Days and weeks of drill and practice, focused on rote learning that serves only to make students perform better on a test, goes against what research tells us about effective learning. In focusing on discrete information or skills, students have few opportunities to draw on their prior knowledge, to learn in authentic settings, and to explore and investigate so as to understand new information in meaningful contexts. Research shows us that prior knowledge is critical for student learning. Drilling students to perform can kill learning. We believe educational professionals must be held accountable, but they should be held accountable for student learning, not just test performance. If we are content simply to focus on performance, then let's continue to devote each winter to test preparation. But if we value our students as learners instead of performers, then the time has come to end the winter of our discontent. And we should do it now.

### **What Do You Think?**

Does our position accord with your own experience? That is, did you feel as if you were learning material solely for the purpose of answering questions correctly on a state-mandated test and not for any future meaningful use? If so, how can you prepare your students for these exams and still make the learning experience relevant to their lives? Explore this issue further at the “Challenging Assumptions” section of the textbook's Education CourseMate website.

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## Suggestions for Teaching: Helping Your Students Become Efficient Information Processors

**1 Develop and use a variety of techniques to attract and hold attention, and give your students opportunities to practice and refine their skills in maintaining attention.**

**a. Be aware of what will capture your students' attention.**

The ability to capture your students' attention is affected by characteristics of the information itself and the learners' related past experiences. Learners are more likely to attend to things they expect to find interesting or meaningful. It is also true that human beings are sensitive to abrupt, sudden changes in their environment. Thus anything that stands out, breaks a rhythm, or is unpredictable is almost certain to command students' attention.

### Examples

- Print key words or ideas in extra-large letters on the board.
- Use colored chalk to emphasize important points written on the board.
- When you come to a particularly important part of a lesson, say, "Now really concentrate on this. It's especially important." Then present the idea with intensity and emphasis.
- Start off a lesson with unexpected remarks, such as, "Imagine that you have just inherited a million dollars...."

**b. To maintain attention, emphasize the possible utility of learning new ideas.**

Although it is possible to overdo attempts at making the curriculum relevant, it never hurts to think of possible ways of relating school learning to the present and future lives of students. When students realize that the basic purpose of school is to help them adapt to their environment, they are more likely to pay close attention to what you are trying to do.

### Example

- Teach basic skills—such as arithmetic computation, arithmetic reasoning, spelling, writing, and reading—as part of class projects that relate to students' natural interests (for example, keeping records of money for newspaper deliveries; measuring rainfall, temperature, and wind speed; writing letters to local television stations to express opinions on or request information about television shows).

**2 Point out, and encourage students to recognize, that certain bits of information are important and can be related to what they already know.**

Attention is one control process for the sensory register; the other is recognition. Sometimes the two processes can be used together to induce students to focus on important parts of material to be learned. Sometimes you can urge your students to recognize key features or familiar relationships on their own.

### Examples

- Say: "This math problem is very similar to one you solved last week. Does anyone recognize something familiar about this problem?"
- Say: "In this chapter, the same basic point is made in several different ways. As you read, try to recognize and write down as many variations on that basic theme as you can."
- Give students opportunities to express ideas in their own words and relate new knowledge to previous learning.
- Have students practice grouping numbers, letters, or classroom items according to some shared feature, such as odd numbers, multiples of five, letters with circles, or things made of wood.

**3 Show students that they can become more efficient learners by combining previously unrelated facts and concepts into larger chunks.**

Do you recall our description of short-term memory being limited to about five to nine items, or chunks, of information at any point in time? (If you don't, perhaps you should take that as a cue to pay particularly close attention to the contents of this chapter.) We also said that this limit could be fudged somewhat by taking advantage of the principle of chunking. Basically, this involves creating associations between what you're trying to learn and what you already have in long-term memory. In this way, you can take what may have been four or five separate pieces of information and reduce them to one piece.

The power of chunking information into meaningful units was dramatically demonstrated in a study conducted with a single college student of average memory ability and intelligence (Ericsson, Chase, & Faloon, 1980). Over 20 months, he was able to improve his memory for digits from seven to almost 80! Being a track and field buff, he categorized three- and four-digit groups as running times for imaginary races. Thus 3,492 became "3 minutes and 49.2 seconds, near world-record time." Number groups that could not be encoded as running times were encoded as ages. These two chunking techniques accounted for almost 90% of his associations. Part of the reason why chunking works is that it reduces the load

on memory. Through combining previously unrelated bits of information into larger units, we actually have less to learn. The other part of the reason is that it creates more coherent and meaningful units, which are easier to recall. If at all possible, try to include lessons on, and opportunities for students to practice, chunking.

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#### **4 Take advantage of the power of distributed practice.**

If you knew you were going to be tested over the contents of this chapter a few days from now, would you wait until the day before the test and then read the entire chapter a few times, or would you read about one third of the chapter each day, with a quick review several hours later of what you had read, for each of three days before the exam? If you opted for the first approach, you would be engaging in what psychologists call *massed practice*. If you chose the second approach, you would be engaging in *distributed practice*. Would your choice make any difference in your test score? Almost certainly. The superiority of distributed over massed practice for a wide range of materials and learners is well established in the research literature (see, for example, Cepeda et al., 2009; Dempster, 1988; Rohrer & Pashler, 2010; Seabrook, Brown, & Solity, 2005).

Now turn this example around and picture yourself as a primary grade teacher who is writing out a lesson plan to teach the beginning reading skill of grapheme–phoneme (letter–sound) correspondences for 30 minutes each day for the coming week. Your students will perform better on a subsequent test if you divide your lessons into three 10-minute sessions a day rather than one 30-minute session. Distributed practice works for the same reason that chunking works: It reduces the demand on memory.

If your students are intellectually ready to direct their own learning, you should tell them about the relative merits of distributed versus massed practice. Most students not only are unaware of the benefits of distributed study periods but also go to considerable lengths to block or mass the study time devoted to a particular subject, even when that tactic is a hindrance rather than a help (Rohrer & Pashler, 2010).

#### **5 Organize what you ask your students to learn, and urge older students to organize material on their own.**

At least some items in most sets of information that you ask your students to learn will be related to other items, and you will find it desirable to call attention to interrelationships. The experiment by Bower, Clark, Lesgold, and Winzenz (1969) described earlier, in which one group of students was given a randomly arranged set of items to learn and another group was presented the same items in logically ordered groups, illustrates the value of organization. By placing related items in groups, you reduce the number of chunks to be learned and also make it possible for students to benefit from cues supplied by the interrelationships between items in any given set. And by placing items in logical order, you help students grasp how information at the beginning of a chapter or lesson makes it easier to learn information that is presented later.

#### **Examples**

- If students are to learn how to identify trees, birds, rocks, or something similar, group items that are related (for example, deciduous trees and evergreen trees). Call attention to distinctive features and organizational schemes that have been developed.
- Print an outline of a chapter on the board, or give students a duplicated outline, and have them record notes under the various headings. Whenever you give a lecture or demonstration, print an outline on the board. Call attention to the sequence of topics, and demonstrate how various points emerge from or are related to other points.

#### **6 Make what students learn more meaningful by presenting information in concrete, visual terms.**

To avoid blank stares and puzzled expressions from students when you explain an idea in abstract terms, try using representations that can more easily be visualized. Concrete analogies, for example, offer one effective way to add meaning to material. Consider someone who has no knowledge of basic physics but is trying to understand a passage about the flow of electricity through metal. For this person, statements about crystalline lattice arrays, free-floating electrons, and the effects of impurities will mean very little. However, such abstract ideas can be explained in more familiar terms. You might compare the molecular structure of a metal bar to a Tinkertoy arrangement, for example, or liken the effect of impurities to placing a book in the middle of a row of falling dominoes. Such analogies increase recall and comprehension (Royer & Cable, 1975, 1976).

You should also consider using what are called graphical displays. These are visual-symbolic spatial representations of objects, concepts, and their relationships. Examples of graphical displays include diagrams, matrices, graphs, concept maps, and charts.

#### **Examples**

- When you explain or demonstrate, express complex and abstract ideas in several different ways. Be sure to provide plenty of examples.
- Use illustrations, diagrams, and concept maps.
- Make sure the type of visual display used is consistent with the goal of a lesson. For example, when the goal is to understand a cause-and-effect relationship, diagrams that show relationships among objects or concepts should be used; but when the goal is to learn about changes over time, as in plant or animal growth, animation is a better choice than a static display.

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## LO4 Technology as an Information-Processing Tool

Many school tasks place strenuous demands on students' information-processing skills because they involve a considerable amount of new and somewhat abstract information. Computer-based technology can lighten this burden by representing information in meaningful ways and letting students manipulate ideas in realistic settings. For instance, software programs can help a learner grasp an idea for a musical composition, see the structure of her writing plans, watch chemical molecules react, or provide complex environments, complete with problems that need solutions.

But as you read through this section, please keep in mind what we said earlier about technology and other teaching tools: There is no one-size-fits-all solution to the challenge of teaching others. Technology, as useful as it can be for helping you achieve certain goals, has potential costs. Here's one example of what we mean. Because human beings are limited in how much information we can process at any point in time, students



**Web 2.0 technologies can enable children from different cultures to share experiences in shared virtual environments.** Eye Ubiquitous/Alamy photolibrary.com

can easily become overloaded, lose track of the point of an assignment, and be unable to recall much of the material they encounter as they read and click on the links of web pages and hypermedia programs (Carr, 2010). How do we know this is so? Research (e.g., Greenfield, 2009; Ophir, Nass, & Wagner, 2009) has demonstrated this outcome many times. In one case, a group of students watched a news anchor read stories while headlines about sports, weather, and other news of the day slowly crawled along the bottom of the screen. The other group watched the same broadcast but with the news crawl taken out. Students in the first group recalled significantly fewer facts about the stories read by the anchor than did students in the second group (Greenfield, 2009). The solution for teachers is twofold. First, teach students how to be disciplined and purposeful users of technology. Second, choose hypermedia programs (those that contain print, pictorial,

and/or animated sources of information with links to other pages that can be examined in any order the learner chooses) that have the smallest number of features that will still allow you to accomplish your instructional goal.

### **Technology Tools for Writing**

Because of its flexibility, technology can be used in a variety of ways to make writing less threatening and to increase both the quantity and quality of students' writing. Here's just one example: In classrooms where computers are networked, teachers can use a technique called an electronic read-around. Sitting at separate computers, each student writes on a topic the teacher gives. Each student then clicks on an icon representing another student's computer, reads what that student wrote, and provides feedback in a different font at the end of the document. This process is repeated until each student has read and commented on each other student's text. Students then use the comments to revise and edit their own pieces (Strassman & D'Amore, 2002).

### **Technology Tools for Reading**

As with writing, the use of electronic support systems to increase students' reading skills has increased around the world (Lai, Chang, & Ye, 2006; Llabo, 2002). In comparison with primary grade students who read a print version of a story, students who listened to a story from a CD-ROM storybook significantly increased their sight word vocabulary, reading level, and ability to retell the story accurately and completely (K. I. Matthew, 1996; McKenna, Cowart, & Watkins, 1997). When third graders had to read a CD story themselves but were able to use such other features as clicking on words and illustrations to obtain pronunciations and definitions, their retelling scores did not differ from those of children

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who read a print version, but they did score significantly higher on comprehension questions (Doty, Popplewell, & Byers, 2001).

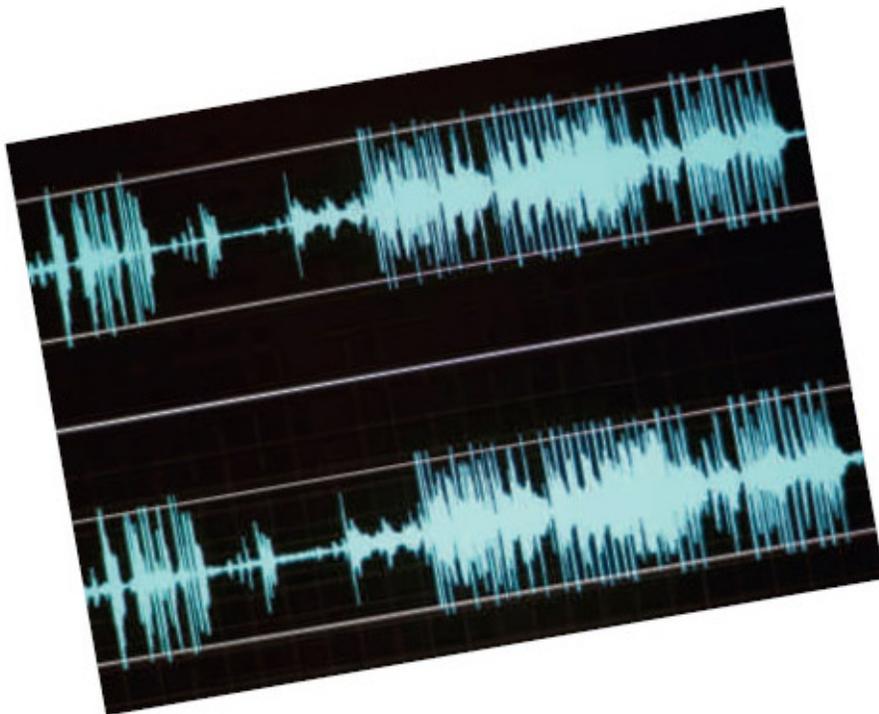
### **Technology Tools for Science and Math**

In mathematics and science, Marcia Linn (1992) and other prominent researchers have argued that students should spend less time manually calculating and plotting data and more time using technology to summarize and interpret data, look for trends, and predict relationships. To help teachers put this philosophy into practice, Linn and others created the Web-Based Inquiry Science Environment (WISE) Project (<http://wise.berkeley.edu>). Based largely on constructivist learning principles and 15 years of classroom research (Slotta & Linn, 2009), the WISE website contains a variety of science projects that teachers can adapt to local curricula and to state and national standards. The overarching goal of the WISE learning environment is to help students make connections among science ideas rather than memorize isolated facts whose relevance is not understood and that are soon forgotten. For each project, students have to locate relevant information on the web, record and organize their findings in an electronic notebook, and participate in online discussions to refine their procedures and conclusions. The Houses in the Desert project, for example, requires pairs of middle school students to design a desert house that will be comfortable to live in. Using resources available on the web, students have to (among other things) analyze the suitability of various materials for walls, roofs, and windows and perform a heat-flow analysis. The WISE site also allows students to compare climate data in a desert with climate data from their own community (M. C. Linn & Slotta, 2000).

### **Technology Tools for Art and Music**

As you may be aware, computer tools are also being used in the fine and performing arts. Art education, for instance, benefits from electronic tools such as the draw and paint modules that quickly erase or alter ideas. Students can use these tools to mimic the branching, spiraling, and exploding structures of nature (as seen, for example, in trees, vines, and flowers) (Lach, Little, & Nazzaro, 2003), and they can create abstract patterns by repeating, changing the horizontal and vertical orientation, and changing the alignment of a basic pattern (Yoerg, 2002). With these tools, students can also draw objects in two-point perspective (B. Patterson, 2002) and create stylized portraits by using shadows, contour lines, stippling, and cross-hatching (Mathes, 2002).

For the music classroom, there are tools such as digital oscilloscopes that help students understand relationships between pitch and wavelength. In addition, CD technology can be used to present graphical representations of notes as they are played, sections of which can be saved and compared with other verses of the same song or with other songs, thereby helping students understand themes and patterns in music. Moreover, computer tools such as musical instrument digital interface and formal instrumental music tuition allow students to compose at the keyboard, play a musical instrument and record it on a computer, and play one part of a multi-instrument piece while the program plays the other instruments (Peters, 2001; Reninger, 2000; Seddon & O'Neill, 2006). Students can explore concepts of pitch, duration, sound combination, repetition, and melody and engage in the process of musical thinking.



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Virtual environments provide rich content and context that can support collaborative learning.

## **Multimedia, Hypermedia, and Virtual Environments**

As mentioned in previous chapters, multimedia encyclopedias, databases, and libraries provide students with a wide variety of information resources.

### **Multimedia Tools**

Multimedia tools offer multiple views (text, photographs, digitized video, animation, sound) of difficult concepts that can enrich student understanding of the topic. The use of multimedia tools is related to such information-processing concepts as meaningful learning, the dual coding of information, the use of visual imagery, and elaborative rehearsal (Leacock & Nesbit, 2007; R. E. Mayer & Moreno, 2002, 2003; S. K. Reed, 2006).

### **Hypermedia Tools**

Hypermedia technology exists when multimedia information can be nonsequentially

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accessed, examined, and constructed by users, thereby enabling them to move from one information resource to another while controlling which options to take (Grabe & Grabe, 2007). There are clear advantages to hypermedia, such as the richness of the network of ideas, the compact storage of information, the rapid nonlinear access to information, the flexible use of information, and the learner's control over the system. Not surprisingly, it has been suggested that hypermedia tools radically alter the way people read, write, compute, and perhaps even think (Keengwe, Onchwari, Wachira, 2008; S. C. Yang, 2001).

### **Virtual Environments**

By combining multimedia and hypermedia capabilities, researchers and designers have developed rich, complex virtual environments in which multiple learners can engage individual or collaborative learning experiences. (We mentioned these environments, called multiuser virtual environments, in Chapter 2.) One such environment is Quest Atlantis (<http://atlantis.crlt.indiana.edu>), which has been well researched and documented (Barab, Gresalfi, et al., 2009; Barab, Scott et al., 2009; M. Thomas, Barab, & Tuzun, 2009) and continues to attract much attention from researchers, teachers, parents, and organizations such as the National Science Foundation, the MacArthur Foundation, and NASA. We will revisit Quest Atlantis in Chapter 10, but it is mentioned here as an example of how information across a variety of content areas can be engaged by students.

The virtual world of Quest Atlantis includes various kinds of learning experiences for students: quests, missions, and units. Quests are tasks that are tied to particular areas of the curriculum to ensure that students acquire content knowledge. Missions combine a number of tasks and other learning opportunities that are integrated through general problem-solving exercises and driven by a narrative or story line. Units provide teachers with lesson plans that combine virtual and face-to-face learning activities. For example, the Taiga Water Quality Unit in Quest Atlantis challenges students to address an ecological situation that has resulted in dead and dying fish in Taiga Park. Students acquire information by navigating through the park to collect data and evidence to make a recommendation about how to solve the problem. After deciding what action to take, students then travel 20 years into the future to see the consequences of their decisions.

WHAT ELSE? *RIP & REVIEW CARDS IN THE BACK*

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## Chapter in Review 8: Information-Processing Theory: Key Terms

- **information-processing theory** An area of study that seeks to understand how people acquire, store, and recall information, and how their current knowledge guides and determines what and how they will learn.
- **sensory register (SR)** The primary memory store that temporarily records (for 1 to 3 seconds) an incoming flow of data from the sense receptors.
- **recognition** A cognitive process that involves noting key features of a stimulus and relating them to previously stored information in an interactive manner.
- **attention** The selective focusing on a portion of the information currently stored in the sensory register.
- **short-term memory (STM)** The second temporary memory store, which holds about seven bits of information for about 20 seconds. Also called *working memory*.
- **maintenance rehearsal** A rather mechanical process that uses mental and verbal repetition to hold information in short-term memory for some immediate purpose. Also called *rote rehearsal* or *repetition*.
- **elaborative rehearsal** A process that consciously relates new information to knowledge already stored in long-term memory. Also called *elaborative encoding*.
- **meaningful learning** Learning that occurs when new information or activities are made relevant by relating them to personal interests and prior experiences or knowledge.
- **dual coding theory** A theory of elaboration that states that concrete objects and words are remembered better than abstract information because they are coded in memory as both visual images and verbal labels, whereas abstract words are only encoded verbally.
- **long-term memory (LTM)** The storehouse of permanently recorded information in an individual's memory.
- **schemata** Plural of *schema*; abstract information structures by which our store of knowledge is organized in long-term memory. *Schemas* is another plural form.
- **encoding specificity principle** The idea that material is more likely to be recalled when some part of it that was stored in long-term memory is available as a retrieval cue.
- **massed practice** An approach to learning that emphasizes a few long, infrequently spaced study periods.
- **distributed practice** The practice of breaking up learning tasks into small, easy-to-manage pieces that are learned over several relatively brief sessions.
- **metacognition** Knowledge about the operations of cognition and how to use them to achieve a learning goal.

## Chapter in Review 8: Information-Processing Theory: Chapter Summary

**LO1 Explain what is meant by the information-processing view of learning.**

- Information-processing theory attempts to explain how individuals acquire, store, recall, and use information.

**LO2 Describe the various components and processes that make up the multistore model of information processing.**

- A popular model of information processing is composed of three memory stores and a set of control processes that determine the flow of information from one memory store to another. The memory stores are the sensory register, short-term memory, and long-term memory. The control processes are recognition, attention, maintenance rehearsal, elaborative rehearsal, and retrieval.
- The sensory register holds information in its original form for 1 to 3 seconds, during which time we may recognize and attend to it further.
- Recognition involves noticing key features of a stimulus and integrating those features with relevant information from long-term memory.
- Attention is a selective focusing on a portion of the information in the sensory register. Information from long-term memory influences what we focus on.

- Short-term memory holds about seven bits of information for about 20 seconds (in the absence of rehearsal). It is often called working memory because it is where various encoding, organizational, and retrieval processes occur. Working-memory capacity appears to be strongly related to proficiency of learning.
- Information can be held in short-term memory indefinitely through the use of maintenance rehearsal, which is rote repetition of information.
- Information is transferred from short-term memory to long-term memory by the linking of the new information to related information in long-term memory. This process is called elaborative rehearsal.
- Elaborative rehearsal is based partly on organization. This involves grouping together, or chunking, items of information that share some important characteristic.
- Elaborative rehearsal is also based on meaningfulness. Meaningful learning occurs when new information that is clearly written and logically organized is consciously related to information the learner currently has stored in long-term memory.
- Long-term memory is thought by some psychologists to be an unlimited and essentially permanent storehouse of information.
- Many psychologists believe the information in long-term memory is organized in the form of schemata. A schema is a generalized abstract structure of information. When schemata are absent or crudely formed, learning and recall problems occur.
- People forget previously learned information for any of several reasons, including inadequate learning, nonmeaningful learning, insufficient opportunities for retrieval, interference from similar material, and lack of retrieval cues.

### **LO3 Define metacognition and explain how it affects the learning process.**

- Metacognition refers to any knowledge an individual has about how humans think and how those processes can be used to achieve learning goals. It is typically thought of as being composed of declarative, conditional, and procedural knowledge components.
- Metacognition increases gradually with experience. This helps explain why junior high and high school students are more flexible and effective learners than primary grade students.

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### **LO4 Describe the ways technology can help students improve how much and how well they learn different subjects.**

- Contemporary computer-based technology supports information processing by helping students to organize and mentally represent ideas, write more clearly, better comprehend text, interpret scientific and mathematical data, understand musical patterns, and solve problems.

### **Chapter in Review 8: Information-Processing Theory: Reflection Questions**

1. Thinking back on my elementary, middle school, and high school education, what ideas and skills can I still recall? Why am I still able to retrieve this information?
2. Looking back on the suggestions for teaching presented in this chapter, how many of these have I been exposed to at some point in my career as a student?

### **Chapter in Review 8: Information-Processing Theory: Review Questions**

1. What are the three memory stores?
2. How long does short term memory last?
3. What does research say about the use of visual imagery in learning?
4. What are some possible explanations as to why forgetting occurs?
5. What are three components of metacognition?
6. What are two strategies teachers can employ to ensure technology is used most effectively in the classroom?

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