In my many years of college teaching, I've sometimes had students approach me after receiving a low score on one of my exams. "I studied so *hard!*" a student might whine, displaying a look of frustrated desperation. "I studied twice as long as my roommate did, yet my roommate got an A and I got a C–!"

Storing information in long-term memory and retrieving it later can be a tricky business. If two students are equally motivated to learn class material, the difference between them may be the result of their storage and retrieval processes. After several decades of talking with college students about how they typically study, I've come to the conclusion that many of them have little or no understanding of how they might best learn and remember new information.

Even when students effectively store information in their long-term memories, they don't always learn what their teachers *think* they're learning. For example, when my daughter Tina was in fourth grade, she came home one day complaining about a song she was learning in the school choir. "It has bad words in it, Mom," she said. I was quite surprised to learn that she was talking about "America the Beautiful," but then she recited the guilty line from the second verse:

All the bastard cities gleam.

After shuddering at the richness of my daughter's vocabulary, I patiently explained that the line in question was actually "Alabaster cities gleam." Two weeks later, the rest of the family went to hear Tina's choir performing in a concert. After hearing the children sing "O beautiful for spacious skies"—the first line of the song Tina had complained about—6-year-old Alex turned to me and whispered, "Why are they singing about spaceship skies?"

Long-term memory provides a mechanism for saving information over a relatively long time period. It also provides a knowledge base from which to interpret new information. As we'll see, people often store incoming information in long-term memory by relating it to things they already know. Various individuals may store the same information differently, then, because their existing knowledge bases are different. Alex had never heard the word *spacious* before, but *spaceship* was a frequent word in his world of science-fiction children's books and cartoons. Similarly, Tina was unfamiliar with *alabaster,* but . . . well, you get my drift.

In this chapter, we'll explore the many processes involved in long-term memory storage and retrieval—processes in which *working* memory can also be a key player. Then, in Chapter 9, we'll look at the nature of the knowledge that resides in people's long-term memories and discover that it often includes some only-partly-right and mostly-wrong ideas.

Storage as a Constructive Process

Imagine, for a minute, that your mind works like a video camera, such that you can record everything you see and hear. To remember a particular event, then, you'd simply find and replay the right mental "video," and you'd be able to remember the event as completely and accurately as if you were reliving it. Studying for an exam would be easy, you might think—no need for reading the textbook more than once or for mindless memorization of meaningless facts.[1]

[1]As I write this chapter in 2014, Google Glass has just become available to the public, so this memory-as-video-camera idea may become reality for many people before too long—but *not* because of our neurological hardware.

Unfortunately, our minds aren't accurate recorders of life events. As we discovered in Chapter 7, we can process only a small amount of information in working memory at any one time, and so we quickly lose most of what we've stored in our sensory registers. In a manner of speaking, most of the information we receive from the environment goes in one ear (or eye) and out the other. In part because we retain such a small percentage of the information we receive, many learning theorists believe that long-term memory storage often involves a process of *construction,* whereby we use the bits and pieces of the information we do retain to build a reasonable understanding of the world around us.

Examples of Construction in Action

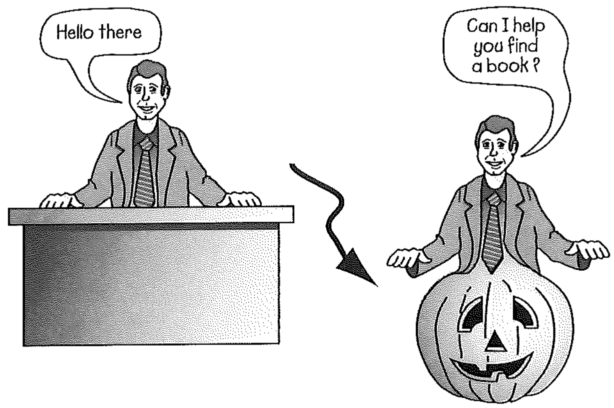
At any given point in time, our interpretation of the environment (**perception**) is usually both less and more than the information we actually receive from the environment (**sensation**). Perception is *less* than sensation because people can't possibly interpret all the information that bombards their sensory receptors at any given moment. Right now, as you're looking at this book, light waves are bouncing off the page and hitting the light-sensitive cells in the retinas of your eyes. At the same time, you may also be receiving light waves from a table at which you're working, a carpet on the floor, and pictures on the walls. Your ears are probably sensing many sound waves, perhaps from an air conditioner, a nearby conversation, or traffic outside your window. Perhaps a certain smell is drifting through the air or a certain taste lingers in your mouth. It's neither necessary nor possible for you to interpret *all* of these sensations, so you'll attend to some of them and ignore the others.

But perception is also much *more* than sensation, because sensation alone provides insufficient information for adequate interpretations of ongoing events. It appears that people use the data their sensory receptors give them to put together, or construct, an overall perception of any given situation (Z. Lin & He, 2012; Myin & O'Regan, 2009; Neisser, 1967). As an example, consider the fact that our eyes don't provide a continual report of visual stimulation; rather, they jump from one focal point to another, taking periodic "snapshots" of the visual field. These jumps in focus, or **saccades**, occur four or five times a second, with visual sensation occurring primarily during the rest periods between them (Abrams, 1994; Irwin, 1996). If we receive only four or five snapshots of visual information each second, our visual world should appear jerky and erratic, much as an old-time black-and-white movie does. The fact that we instead see smooth-flowing motion is due, in large part, to the mental "filling in" that occurs as our minds interpret visual sensations. (This principle should remind you of the Gestalt concept of *closure*, described in Chapter 6.)

Even if human eyes functioned 100% of the time, they would give us an incomplete picture of the environment, and we would have to mentally fill in the information that we didn't sense. For example, imagine walking into a bookstore and seeing the store clerk behind the counter. Your senses are telling you only about the clerk's head and upper torso, yet you perceive an entire person. You assume that the clerk has a lower torso and two legs, and in fact you'd be quite surprised if you saw a very different lower body—maybe a carved pumpkin—as he emerged from behind the counter.

As another example of construction in perception, look at the three pictures in Figure 8.1. Most people perceive the one on the left as a woman's face and neck, even though many of the woman's features are missing. Do the other two pictures provide enough information for you to

People often make assumptions about what they don't see and may be quite surprised when such assumptions are inaccurate.



construct two more faces? Constructing a face from the right-most picture may take you a while, but I assure you that it can be done.

Consider, too, how much is missing from the spoken language we hear. For example, let's say that you are in a noisy room and hear someone say:

I -an't -ear a -ing in this -lace!

Although you haven't heard everything the person said, you may have enough information to perceive the sentence:

I can't hear a thing in this place!

Even when you do hear everything the speaker says, what you *really* hear is a continuousstream-ofsoundwaves rather than . . . separate . . . words . . . spoken . . . like . . . this. Only when you're familiar with the particular language being spoken can you mentally divide that one long sound into separate words.

Thanks to constructive processes, different people may perceive and interpret the same object or event differently. For instance, look closely at the picture in Figure 8.2. Describe to

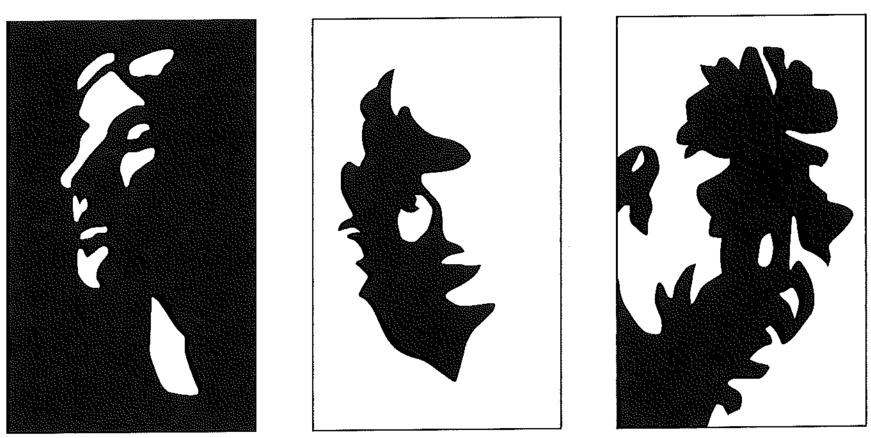
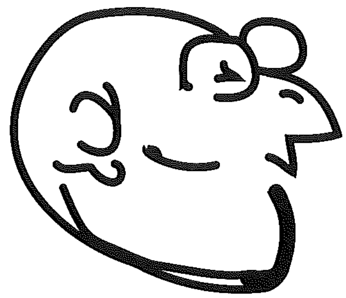


Figure 8.1
Can you construct a person from each of these pictures?

Reprinted from "Age in the Development of Closure Ability in Children" by C. M. Mooney, 1957, *Canadian Journal of Psychology, 11,* p. 220. Copyright 1957 by Canadian Psychological Association. Reprinted with permission.

Figure 8.2
Reprinted from "The Role of Frequency in Developing Perceptual Sets" by B. R. Bugelski & D. A. Alampay, 1961, *Canadian Journal of Psychology, 15,* p. 206. Copyright 1961 by Canadian Psychological Association. Reprinted with permission.



yourself what you see. Notice the shape of the head, the eye, the nose, the mouth, the jaw line. But just what is it that you *do* see? Is this a picture of a man? Or is it some sort of rodent? In fact, it's an **ambiguous stimulus** that can be interpreted in at least two ways. Some people perceive the figure to be a bald man with an overbite, strangely shaped ear, and backward tilt to his head. Others instead see a rat or mouse with a very short front leg and a long tail curling beneath its body (Bugelski & Alampay, 1961).

LONG-TERM MEMORY STORAGE PROCESSES

As you discovered in Chapter 7, some attended-to information is automatically stored in long-term memory even if it's not specifically selected for further processing (recall our discussion of the frequencies of *bacon* versus *pastrami*). But most explicit knowledge—information that people *know* they know and can easily explain—requires not only attention but also conscious mental effort in order to be stored effectively for the long run.

To get a sense of what learners might do in their efforts to gain explicit knowledge, read the following short story, "The War of the Ghosts." Read it silently *one time only,* then cover the page and write down as much of the story as you can remember.

The War of the Ghosts

One night two young men from Egulac went down to the river to hunt seals, and while they were there it became foggy and calm. Then they heard war-cries, and they thought, "Maybe this is a war-party." They escaped to the shore, and hid behind a log. Now canoes came up, and they heard the noise of paddles, and saw one canoe coming up to them. There were five men in the canoe, and they said:

"What do you think? We wish to take you along. We are going up the river to make war on the people."

One of the young men said: "I have no arrows."

"Arrows are in the canoe," they said.

"I will not go along. I might be killed. My relatives do not know where I have gone. But you," he said, turning to the other, "may go with them."

So one of the young men went, but the other returned home.

And the warriors went on up the river to a town on the other side of Kalama. The people came down to the water, and they began to fight, and many were killed. But presently the young man heard one of the warriors say, "Quick, let us go home: that Indian has been hit." Now he thought: "Oh, they are ghosts." He did not feel sick, but they said he had been shot.

> So the canoes went back to Egulac, and the young man went ashore to his house, and made a fire. And he told everybody and said, "Behold I accompanied the ghosts, and we went to fight. Many of our fellows were killed, and many of those who attacked us were killed. They said I was hit, and I did not feel sick."
>
> He told it all, and then he became quiet. When the sun rose he fell down. Something black came out of his mouth. His face became contorted. The people jumped up and cried.
>
> He was dead. (Bartlett, 1932, p. 65)

Now cover the story and write down everything you can remember of it.

Once you've finished, compare your reproduction with the original. What differences do you notice? Your reproduction is almost certainly shorter than the original, with many of the details omitted. Perhaps you added some things, drawing on your prior knowledge to help you make sense of the story, consistent with the construction process described earlier. But you probably maintained the overall gist of the story—its main ideas and events, mostly in their proper sequence.

Using this Native American ghost story, Frederic Bartlett (1932) conducted one of the earliest studies of the long-term memory of meaningful verbal information. Bartlett asked his students at England's Cambridge University to read the story twice, then to recall it at various times later on. Students' recollections differed from the actual story in a number of ways:

1. *The words themselves were changed.* In other words, recall wasn't verbatim.
2. *The focus was on significant events that contributed to the plot line.* Some details were retained, especially ones that were either quite striking or essential to the story. For example, students often remembered such things as "something black came out of his mouth"—this is an odd thing to happen to someone—and "he was dead." In contrast, many unimportant details were left out. For instance, students frequently omitted such story elements as "a town on the other side of Kalama" and "the young man . . . made a fire."
3. *Parts of the story were distorted, and additional information was inserted to make the story more logical and consistent with English culture.* For example, people rarely go "to the river to hunt seals," because most seals are saltwater animals and most rivers have fresh water. Thus, students might say that the men went to the river to *fish*. Similarly, the supernatural element didn't fit comfortably with the religious beliefs of most Cambridge students and so was often altered. For example, notice the additions and distortions in this recollection, written by a student six months after he had read the original story:

   > Four men came down to the water. They were told to get into a boat and to take arms with them. They inquired, "What arms?" and were answered "Arms for battle." When they came to the battle-field they heard a great noise and shouting, and a voice said: "The black man is dead." And he was brought to the place where they were, and laid on the ground. And he foamed at the mouth. (Bartlett, 1932, pp. 71–72)

   The main idea of the story—a battle—is retained. But after six months, the story has been so distorted that it's barely recognizable.
4. *There was a tendency to explain as well as describe events.* For example, one student insisted on explaining events in parentheses:

   > The young man did not feel sick (i.e., wounded), but nevertheless they proceeded home (evidently the opposing forces were quite willing to stop fighting). (Bartlett, 1932, p. 86)

Such findings reveal several qualities about long-term memory storage: It's selective, constructive, occasionally distortive, and to some degree dependent on a learner's existing knowledge. Furthermore, it appears that human beings are motivated to make sense of—that is, to *find meaning* in—what they see and hear.

The preceding chapter introduced you to the distinction between *declarative knowledge*—knowledge about how things are, were, or will be (e.g., facts, figures, events)—and *procedural knowledge*—knowledge about how to do things (e.g., motor skills, problem-solving techniques, study strategies). Storing declarative knowledge and procedural knowledge may involve somewhat different, although overlapping, processes. In the upcoming sections, we'll look at several cognitive processes that may possibly be involved in long-term memory storage, either separately or in combination: rehearsal, meaningful learning, internal organization, elaboration, and visual imagery. In examining these five processes, we'll focus primarily on the acquisition of declarative knowledge. In a subsequent section, we'll consider how such processes may also be involved in the acquisition of procedural knowledge.

Rehearsal

You should recall from Chapter 7 that **rehearsal**—verbally repeating something over and over in a short time period—can be an effective way of maintaining information in working memory indefinitely. In their early dual-store model of memory, Atkinson and Shiffrin (1971) proposed that rehearsal is also a good method for storing information in long-term memory, and there's some evidence for their idea. Several early studies revealed that people remember frequently rehearsed items better than less frequently rehearsed ones (T. O. Nelson, 1977; Rundus, 1971; Rundus & Atkinson, 1971). Yet other theorists have argued that rehearsal leads to effective long-term memory storage only if, in the process, learners associate the new information with existing knowledge—in other words, if rehearsal also involves *meaningful learning* (e.g., Baddeley, Eysenck, & Anderson, 2009; Craik & Watkins, 1973; Watkins & Watkins, 1974).[2]

Many, many times I've seen students engage in simple repetition when they study new material. This process—often called **rote learning** or, in everyday lingo, *memorizing*—emphasizes the learning of verbatim information. Young children (e.g., elementary school students) are especially likely to use rehearsal when trying to learn and remember new facts (Cuvo, 1975; Gathercole & Hitch, 1993; Lehmann & Hasselhorn, 2007). I've observed high school and college students using it as well, sometimes in the form of self-constructed flashcards. However, the four storage processes we examine next—meaningful learning, internal organization, elaboration, and visual imagery—tend to be *much* more effective.

Meaningful Learning

Look at this string of 15 letters:

MAIGUWRSENNFLOD

And now look at this string:

MEANINGFULWORDS

---

[2]Finding meaning in rehearsed items is sometimes referred to as *elaborative rehearsal*.

Both strings are the same length, and both contain exactly the same letters. But you'll almost certainly agree that the second list is easier because you can relate it to words you already know. In the same way, my daughter Tina related a phrase from "America the Beautiful" to her existing knowledge about the world—which unfortunately included *bastard* but not *alabaster*—as did my son Alex, who heard *spaceship skies* instead of *spacious skies.* By relating new information to knowledge already stored in their long-term memories, people find *meaning* in the information. This process of **meaningful learning** is what we're referring to when we talk about *understanding* or *comprehension.*

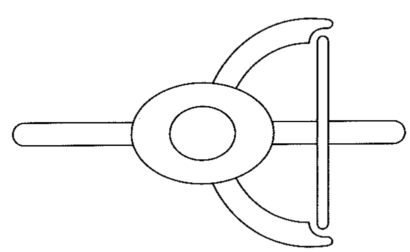
Meaningful learning facilitates both storage and retrieval: Information is stored more quickly and remembered more easily (J. R. Anderson, 2005; Craik, 2006; Mayer, 1996). For example, when learning their lines in a script, many experienced actors begin by reading through the script numerous times to get a general sense of their character's underlying motives and needs; they then use their understanding of the character to *make sense* of the specific words the script calls for (Noice & Noice, 1996). As another example, consider the following passage from an experiment by Bransford and Johnson (1972):

> The procedure is actually quite simple. First you arrange things into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step, otherwise you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important, but complications can easily arise. A mistake can be expensive as well. At first the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell. After the procedure is completed one arranges the materials into different groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However, that is part of life. (p. 722)

You may have had trouble making sense of the passage because you didn't know what it was about. But now try reading it again, this time thinking of it as a description of doing laundry. Bransford and Johnson found that college students who knew the topic of the passage remembered twice as much as those who had no topic with which to connect things.

People can also store nonverbal material more easily when they can find meaning in it. For example, look at the drawing in Figure 8.3. Do you think you could draw it from memory a week from now? Might you be able to remember it more easily if it had the title "Bird's-Eye View of a Cowboy Riding a Bicycle"? The answer to the second question is almost certainly *yes,* because the title would help you relate the picture to familiar shapes, such as those of a bicycle and a cowboy hat (G. H. Bower, Karlin, & Dueck, 1975).

Figure 8.3



Relating new information to *oneself* can have a particularly dramatic effect on learning—a phenomenon known as the **self-reference effect** (Craik, 2006; Heatherton, Macrae, & Kelley, 2004; T. B. Rogers, Kuiper, & Kirker, 1977). For example, in Chapter 7, I told you the month and day I was born. Can you recall what my birthday is? If you can, there's a good chance that it's close in the year to your own—perhaps a few days before or after it (Kesebir & Oishi, 2010). To refresh your memory, I was born on August 22nd. I myself am quite good at remembering the birthdays of two friends who were born nine days earlier than I was (on the 13th) and the birthday of another friend born the day after (the 23rd). I can also remember a coauthor's birthday because, although she was born in January, it was the *22nd* of January, and I'm especially partial to other "22" birthdates. As for those friends born in November or March, I'm pretty clueless, with one exception: A friend in Colorado was born on March 4th, the only day of the year that can be interpreted as a meaningful command: "March forth!"

Internal Organization

A body of new information is stored more effectively and remembered more completely when its various pieces are interconnected in some way—that is, when the new information has **internal organization**. For example, Figure 8.4 shows how you might organize the kinds of reinforcers and punishments described in Chapter 3. In fact, people seem to have a natural tendency to organize and integrate the information they receive, typically based on organizational schemes they've previously acquired. For instance, in our discussion of verbal learning research in Chapter 6, we noted that people who are asked to remember a list of words often put the words into categories while learning them (e.g., retrieving all the animals together and all the vegetables together). You may also recall the Bransford and Franks (1971) study described in Chapter 6, in which students learned that "The ants in the kitchen ate the sweet jelly which was on the table" by integrating the contents of several shorter sentences.

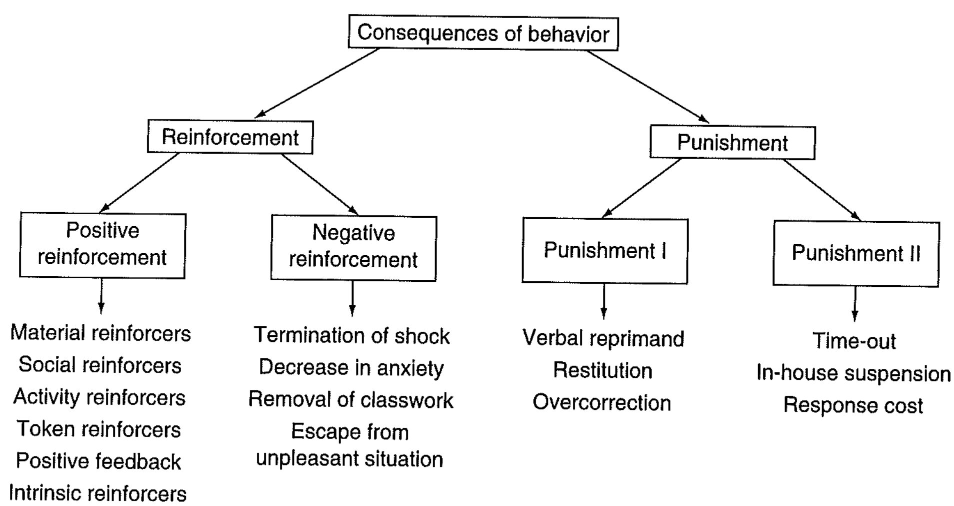


Figure 8.4
Example of a concept hierarchy.

A classic experiment by Bower, Clark, Lesgold, and Winzenz (1969) demonstrates just how dramatic the effects of internal organization can be. College students were given four study trials in which to learn 112 words that fell into four familiar categories (e.g., types of minerals, categories of plants). Some students had words arranged randomly, whereas other students had words arranged in hierarchies similar to the one I've created for reinforcers and punishments (Figure 8.4). After one study trial, students who had studied the organized words could remember more than three times as many words as did students who had studied the randomized words. After four study trials, the students in the organized group remembered all 112, whereas those in the random group remembered, on average, only 70.

Many good students spontaneously organize information as they learn it—for instance, by identifying cause-and-effect relationships among two or more facts—and such learner-generated organization can be quite effective (e.g., Britton, Stimson, Stennett, & Gülgöz, 1998; McDaniel & Einstein, 1989; D. S. McNamara & Magliano, 2009). Furthermore, providing students with specific organizational schemes for certain topics can often help them learn classroom material more effectively (e.g., R. K. Atkinson et al., 1999; Mayer, 2010b; Niederhauser, 2008).

Elaboration

When people receive new information, they often impose their own interpretations on it—making assumptions, drawing inferences, and so on—and learn those interpretations right along with the information they've actually been given. In general, **elaboration** involves using prior knowledge to embellish on new information and storing the embellished version. Thus, elaboration is a process of learning *more* than the material presented; I like to think of it as *learning between the lines.*[3] As an example, my son Jeff tells me that when he first heard the expression "losing one's voice" when he was in first or second grade, he deduced that people are born with a finite amount of "voice" that they eventually use up. So as not to waste his own supply, he would only mouth the words—rather than actually sing them—during weekly school choir sessions.

Many studies lead to the same conclusion: People frequently elaborate on the information they receive and then later have trouble distinguishing between the actual truth and their elaborations of it (Graesser & Bower, 1990; M. K. Johnson, Bransford, & Solomon, 1973; Loftus, 2003; Reder & Ross, 1983). As an illustration, read the following passage *one time only:*

> Nancy woke up feeling sick again and she wondered if she really were pregnant. How would she tell the professor she had been seeing? And the money was another problem.
>
> Nancy went to the doctor. She arrived at the office and checked in with the receptionist. She went to see the nurse, who went through the usual procedures. Then Nancy stepped on the scale and the nurse recorded her weight. The doctor entered the room and examined the results. He smiled at Nancy and said, "Well, it seems my expectations have been confirmed." When the examination was finished, Nancy left the office. (J. Owens, Bower, & Black, 1979, pp. 185–186)

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[3]*Meaningful learning* and *elaboration* might strike you as very similar processes, and in fact they overlap enough that theorists sometimes use the two terms interchangeably. In my opinion, it's helpful to distinguish between the two. Whereas meaningful learning involves *connecting* new information to existing knowledge, elaboration also involves *embellishing on* new information.

Did the doctor tell Nancy she was pregnant? No, he did not. Yet in a study conducted by Owens and his colleagues (1979), when students read the passage and then were asked a day later to recall its contents, they "remembered" considerably more than they'd actually read. Many of their recalled elaborations were directly related to Nancy's suspected condition. Other students in the experiment read only the second paragraph of the passage and thus didn't know that Nancy thought she was pregnant; these students added far fewer elaborations.

Sometimes people's elaborated understandings are incorrect ones, perhaps because people are applying certain generalizations to a situation that don't accurately characterize it (J. J. Williams, Lombrozo, & Rehder, 2013). More typically, however, elaboration involves making *correct* assumptions and interpretations; in such cases it facilitates both storage and retrieval. Elaboration appears to be especially effective when it helps tie new information together—that is, when it also helps to internally organize it (Graesser & Bower, 1990; N. C. Hall, Hladkyj, Perry, & Ruthig, 2004; McNamara & Magliano, 2009; Muis & Franco, 2009; Stein & Bransford, 1979).

Occasionally learners elaborate on and integrate new information to the point that—*on their own*—they construct an entirely new idea, concept, procedure, or line of reasoning. When they do so, they may be able to remember the information better than they would have if someone else had presented it to them in a prepackaged format. This phenomenon, known as the **generation effect**, appears to be beneficial primarily in situations where learners engage in greater elaboration of new material than they might otherwise (Mayer, 2010a; McDaniel, Waddill, & Einstein, 1988; D. S. McNamara & Healy, 1995; Wiley & Voss, 1999).

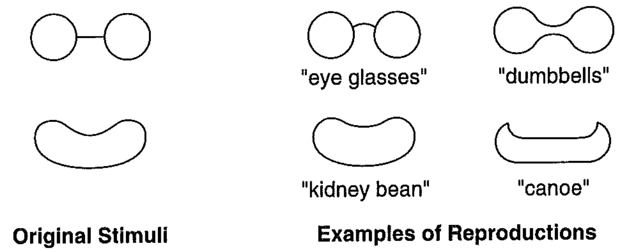
Elaboration probably facilitates long-term memory for several reasons. First, elaborated information is less likely to be confused with other, similar information stored in long-term memory. Second, elaboration provides additional means through which a piece of information can later be retrieved; in a sense, it provides more places to "look" for the information (more on this point later in the chapter). And third, elaboration may help in making inferences about what the information was *likely* to have been if the information itself can't be accurately recalled (J. R. Anderson, 1995, 2005; Hunt & Worthen, 2006).

Visual Imagery

Visual imagery is a mental "picture" that captures how something actually looked or *might* look, and it relies on some of the same specific processes and brain regions that enable visual perception (Behrmann, 2000; Kosslyn, 1994; Speer, Reynolds, Swallow, & Zacks, 2009). Many people of all ages have remarkably accurate memories of visual information. For example, in one study (Konkle, Brady, Alvarez, & Oliva, 2010), college students looked at almost 3,000 scenic photographs in various categories (e.g., ocean waves, golf courses, amusement parks) over a 5½-hour period. After that, they looked at pairs of photos and had to choose which member of each pair they'd previously seen. Their hit rates were fairly high: Even when they had been shown 64 photos of ocean waves or golf courses, they could distinguish between those they'd seen and those they hadn't with 76% accuracy. Furthermore, images can be relatively enduring. For instance, in another study (D. B. Mitchell, 2006), people who viewed a series of pictures for only 1 to 3 seconds in a laboratory experiment showed better-than-chance recognition when asked to identify them *17 years later*!

Figure 8.5
Experimental stimuli and examples of participants' reproductions, from L. Carmichael, Hogan, and Walters (1932).

Adapted from "An Experimental Study of the Effect of Language on the Reproduction of Visually Perceived Form" by L. Carmichael, H. P. Hogan, and A. A. Walters, 1932, *Journal of Experimental Psychology, 15,* p. 80.



People's memory for visual material is often better than it is for strictly verbal material (Dewhurst & Conway, 1994; Edens & McCormick, 2000; Marley, Szabo, Levin, & Glenberg, 2008; Rubin, 2006). And in general, people tend to remember information better when it's presented in *both* verbal and visual forms, provided that the combined information doesn't impose too heavy a cognitive load (Mayer, 2011; Sadoski & Paivio, 2001).

Sometimes learners create their *own* mental images, especially when new information is concrete and can be easily visualized. For instance, when students form visual images while reading stories or listening to explanations of classroom topics, they more effectively understand and remember what they've read or heard (Cothern, Konopak, & Willis, 1990; Dewhurst & Conway, 1994; Sadoski & Paivio, 2001; Sweller, 2008). Furthermore, specifically instructing people to form visual images of what they're studying helps them learn the material more quickly and remember it more effectively (M. S. Jones, Levin, Levin, & Beitzel, 2000; Marley et al., 2008; Pressley, Johnson, Symons, McGoldrick, & Kurita, 1989). Accordingly, imagery provides the foundation for a number of memory strategies called *mnemonics*, which we'll consider in Chapter 12.

Learners of all ages differ considerably in their ability to use visual imagery: Some form images more quickly and easily than others (Behrmann, 2000; J. M. Clark & Paivio, 1991; Kosslyn, 1985). Even for good visualizers, however, visual images tend to be imprecise representations of external objects, with many details omitted, blurry, or altered (Chambers & Reisberg, 1985; S. Reed, 1974; Sadoski & Paivio, 2001). Also, images can be distorted by one's general knowledge about the world, as illustrated in an early experiment by Carmichael, Hogan, and Walters (1932). In this study, adults were asked to remember simple pictures like the ones shown on the left side of Figure 8.5. Two groups were given different sets of labels for the pictures, and the participants tended to remember the pictures in ways that fit the labels. For instance, as you can see in Figure 8.5, the first picture was reproduced differently depending on whether it had been labeled as "eye glasses" or "dumbbells," and recall of the second picture was influenced by its identity as a "kidney bean" or "canoe."

Of the five long-term memory storage processes we've just examined, the last three—internal organization, elaboration, and visual imagery—are clearly constructive in nature. Each of them involves combining new input with previously acquired information to create unique, idiosyncratic understandings. When we organize information, we often use a familiar framework (perhaps a hierarchy of well-known categories) to give new material a meaningful structure. When we elaborate, we use both new information and our existing knowledge to construct a reasonable interpretation of an event. And when we use visual imagery, we often create those images for ourselves based on what we know about how objects typically appear.

How Procedural Knowledge Is Acquired

Some of the procedures people learn—for instance, driving a car with a stick shift, planting flowers, spiking a volleyball—consist primarily of overt behaviors. Other procedures—for instance, writing an essay, solving for *x* in an algebraic equation, surfing the Internet—have a significant mental component. Many procedures involve a combination of physical behaviors and mental activities.

Procedural knowledge ranges from relatively simple actions (e.g., holding a pencil or using scissors) to far more complex skills. Complex procedures usually aren't learned in one fell swoop. Instead, they're acquired slowly over time, often only with a great deal of practice (Beilock & Carr, 2004; Charness, Tuffiash, & Jastrzembski, 2004; Chein & Schneider, 2012; Ericsson, 2003).

People appear to learn many physical procedures primarily as behaviors—in other words, as specific actions that, with practice, are stored and gradually refined (Ennis & Chen, 2011; Féry & Morizot, 2000; van Merriënboer & Kester, 2008; Willingham & Goedert-Eschmann, 1999). Yet some procedures, especially complex ones with a mental component, may also be learned as declarative knowledge—in other words, as *information* about how to do something (J. R. Anderson, 1983a; Beilock & Carr, 2004; Chein & Schneider, 2012). Learners may initially use their declarative knowledge to guide them as they execute a procedure (recall the discussion of self-instructions in Chapter 5). To the extent they must do so, however, their performance is apt to be slow and laborious and require a lot of concentration—that is, it consumes considerable working memory capacity. As learners continue to practice the procedure, their performance gradually becomes faster, easier, and more efficient. People who show exceptional talent in a particular skill—say, in figure skating or playing the piano—typically practice a great deal, usually a minimum of three to four hours a day over a period of 10 years or more (Ackerman, 2007; Ericsson, 1996).

Theorists disagree about how the informational and behavioral aspects of procedural knowledge are interconnected during learning and long-term memory storage. Some theorists (e.g., J. R. Anderson, 1983a, 1987; Beilock & Carr, 2004) have suggested that declarative knowledge is acquired first and, with practice, gradually *evolves* into procedural knowledge. Other theorists (Chein & Schneider, 2012; Willingham & Goedert-Eschmann, 1999) have suggested that people may simultaneously learn *both* information and behaviors in the process of acquiring a new procedure. They quickly learn the informational piece—this takes the form of explicit declarative knowledge—but learn the appropriate behaviors in a more gradual, *implicit* manner. When the behaviors are still imperfect and inconsistent, people pay a lot of attention to what they're doing, and they use their declarative information to help them remember what they need to do (Chein & Schneider, 2012; Gray, 2011). For instance, beginning tennis players might continually remind themselves to "Keep your arm straight" and "Keep your eye on the ball." Such verbal self-support becomes less necessary as learners increasingly fine-tune and master a procedure's behavioral aspects.

Processes previously described for storing declarative knowledge can play a role in acquiring procedural knowledge as well. For instance, verbally rehearsing a sequence of steps in a motor skill enhances people's ability to perform the skill (Vintere et al., 2004; Weiss & Klint, 1987). Illustrations or live demonstrations of a procedure, which presumably foster visual imagery, are also helpful (Kitsantas, Zimmerman, & Cleary, 2000; SooHoo, Takemoto, & McCullagh, 2004). In fact, imagining *oneself* performing an action (e.g., executing a gymnastics skill or a basketball shot) can enhance acquisition of a procedure, although such imagined behaviors obviously aren't as effective as actual practice (Feltz, Landers, & Becker, 1988; Kosslyn, 1985; SooHoo et al., 2004).

To the extent that procedural knowledge has mental as well as physical components—for example, as is true in solving mathematical problems and conducting scientific experiments—meaningful learning and elaboration of relevant declarative information are also important. In particular, learners should understand *why* certain procedures are appropriate and effective (Baroody, Eiland, Purpura, & Reid, 2013; M. Carr & Biddlecomb, 1998; D. Kuhn & Pease, 2008).

FACTORS AFFECTING LONG-TERM MEMORY STORAGE

A variety of factors affect how learners store new information in long-term memory. One important factor is *time:* The neurological underpinnings of new knowledge may require several minutes, hours, or even longer to "firm up" in the brain (recall the discussion of *consolidation* in Chapter 2). But other factors are influential as well. In the next few pages we'll consider several cognitive factors—working memory, prior knowledge, prior misconceptions, and expectations—and several behavioral factors—verbalization, enactment, repetition, and review—that can make a significant difference in how effectively learners store new knowledge for the long run.[4]

Working Memory

For learners to make connections between new information and things they already know—things they've previously stored in long-term memory—they must be *aware* of relationships between the two. In other words, both pieces must be in working memory at the same time (Daneman, 1987; Kalyuga, 2010; Nuthall, 2000; Sweller, 2010). In some cases, new information reminds learners of something they already know, leading them to retrieve that knowledge to working memory. In other situations, another person (e.g., a teacher) might point out the relationships between the new information and previously learned material, thus encouraging retrieval of relevant prior knowledge.

The less working memory capacity learners have available to them, of course, the less "room" they have with which to think about how various bits of information might fit together. For instance, when learners are multitasking—that is, when their working memories are trying to handle two or more tasks at once—they're less likely to store and recall new information effectively (Mayer, 2011; Sweller, 2010; Vergauwe, Barrouillet, & Camos, 2010). And learners who have relatively "small" working memories draw fewer inferences from what they read than do students who have larger-capacity ones (Linderholm & van den Broek, 2002; Oakhill, Cain, & Yuill, 1998).

[4]Notice that I am *not* including any discussion of *learning styles* in this section. Contrary to a widespread belief, much of the evidence cited to substantiate the existence of varying student learning styles doesn't hold up under the scrutiny of other researchers. Furthermore, tailoring particular instructional strategies to students' self-reported styles—which in some cases are nothing more than students' *preferences*—doesn't necessarily enhance academic achievement (e.g., see Kirschner & van Merriënboer, 2013; Kozhevnikov, Evans, & Kosslyn, 2014; Krätzig & Arbuthnott, 2006; Mayer & Massa, 2003; Nieto & Bode, 2008).

Prior Knowledge

People can connect new information to prior knowledge only when they actually *have* knowledge that relates to what they're learning. One of the most important factors affecting long-term memory storage, then, is *what a learner already knows* (e.g., Ausubel, Novak, & Hanesian, 1978; Kintsch, 2009; Shapiro, 2004; Sweller, 2010). Learners who have a large body of information already stored in long-term memory have more ideas to which they can relate their new experiences and so can more easily engage in such processes as meaningful learning and elaboration. Learners who lack relevant knowledge must resort to rehearsal and other inefficient rote-learning strategies (Bandalos, Finney, & Geske, 2003; E. Wood, Willoughby, Bolger, & Younger, 1993). In other words, the rich (in knowledge) get richer, and the poor stay relatively poor.

Numerous studies have illustrated the importance of previous knowledge for encoding and storing new information (Ackerman, 2007; Cromley, Snyder-Hogan, & Luciw-Dubas, 2010b; E. Fox, 2009; Hattie, 2009). As an example, three of my colleagues and I once conducted a study of how well people from different disciplines learn and remember maps (Ormrod, Ormrod, Wagner, & McCallin, 1988). We asked faculty members and students in three disciplines—geography, sociology, and education—to study two maps and then reproduce them from memory. One of the maps, shown in Figure 8.6, depicted a mythical city laid out in usual citylike patterns; that is, its arrangement was *logical*. For instance, notice how the downtown business district can be easily reached from different directions (this is typical), and the mills, lumberyard, and low-income housing are situated near the railroad tracks (also typical). The second map, which depicted several mythical countries near the "Jovian Sea," made no sense. For instance, a river ran *up* into a mountain range, major transportation networks (e.g., highways and train tracks) didn't interconnect, and some large towns seemed to have no roads going to them. We predicted that geographers would remember more of the logical city map than the other two groups because they could use their knowledge of typical urban patterns to engage in meaningful learning; however, they would have no prior-knowledge advantage for the illogical countries map. Our predictions were confirmed: Geographers showed better recall than the other two groups only for the city map. Because we had asked our participants to "think aloud" as they studied the maps, we could also examine the strategies they employed. We frequently heard the geographers trying to make sense of the city map, and they occasionally commented about certain oddities in the countries map. In contrast, our nongeographers used primarily rote-learning strategies, mostly in the form of simple rehearsal.

Other studies have yielded similar results. For example, adults and children who know a lot about a particular sport—say, basketball or soccer—can remember more new facts about the sports than can people who are relatively uninformed about the sport (V. C. Hall & Edmondson, 1992; Kuhara-Kojima & Hatano, 1991; Schneider, Körkel, & Weinert, 1990). Eighth-graders who know a lot about American history engage in more elaboration when they read a history textbook (e.g., they're more likely to make inferences) than classmates who have less history knowledge (Hamman et al., 1995). And middle school students who have a firm understanding of fractions have an easier time with introductory algebra than students who haven't mastered fractions (Booth & Newton, 2012).

So far in this section, much of our focus has been on how prior knowledge affects *how much* people can effectively store and remember. But prior knowledge can also affect *what* people store and remember. Consider the following passage from a study conducted by Anderson, Reynolds, Schallert, and Goetz (1977):

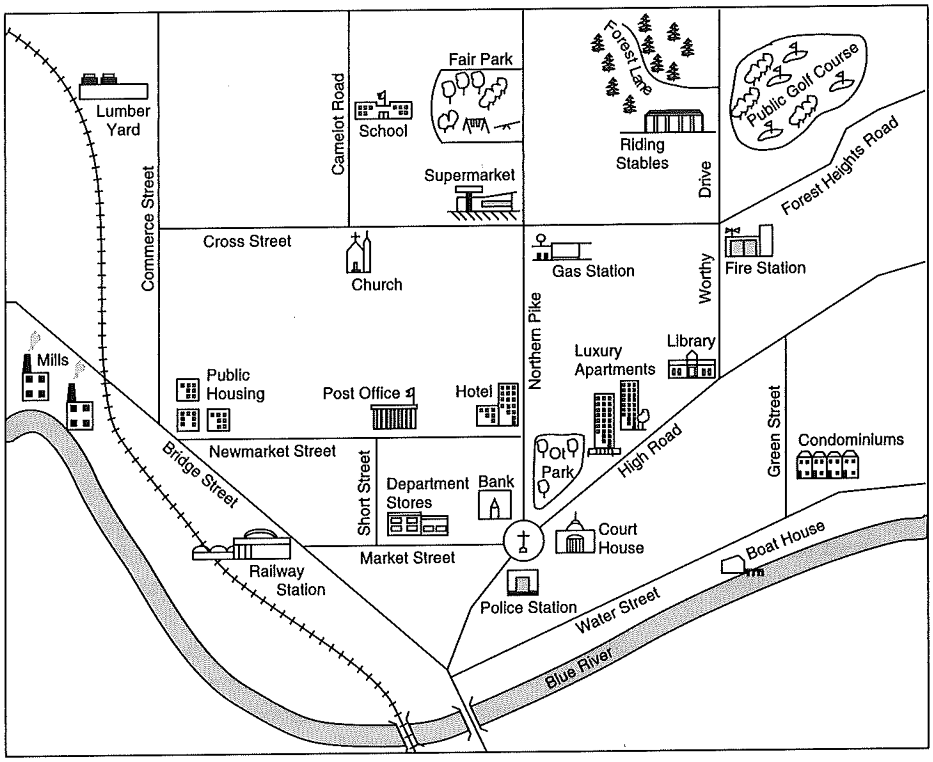


Figure 8.6
The logical city map from Ormrod et al. (1988).
Reprinted from "Reconceptualizing Map Learning" by J. E. Ormrod, R. K. Ormrod, E. D. Wagner, & R. C. McCallin, 1988, *American Journal of Psychology, 101,* p. 428. Reprinted with permission of the University of Illinois Press.

> Rocky slowly got up from the mat, planning his escape. He hesitated a moment and thought. Things were not going well. What bothered him most was being held, especially since the charge against him had been weak. He considered his present situation. The lock that held him was strong but he thought he could break it. He knew, however, that his timing would have to be perfect. Rocky was aware that it was because of his early roughness that he had been penalized so severely—much too severely from his point of view. The situation was becoming frustrating; the pressure had been grinding on him for too long. He was being ridden unmercifully. Rocky was getting angry now. He felt he was ready to make his move. He knew that his success or failure would depend on what he did in the next few seconds. (R. C. Anderson, Reynolds, Schallert, & Goetz, 1977, p. 372)

Is this story about a wrestling match? Or is it about a prison escape? If you read the passage again, you should realize that it could be about either one. In the study by Anderson and colleagues, students' interpretations of the story depended on their academic background. Many physical education majors thought it was about a wrestling match, whereas music education majors—who presumably knew a lot about music but little about wrestling—were more likely to interpret it as a prison escape.

It's entirely possible, however, to have existing knowledge about a topic and yet *not* bring it into play when learning new information about the topic. As noted earlier, a learner will make connections between the "new" and the "old" only if both are simultaneously in working memory. To switch from a dual-store model of memory to an activation model for a moment, we might say that both the new and the old must be *activated* at the same time. As we consider instructional strategies later in the chapter, we'll identify a variety of ways in which teachers might promote meaningful learning and elaboration by activating students' prior knowledge.

Prior Misconceptions

When people engage in elaboration, they use what they already know about a topic to expand on and presumably make better sense of new information. But what happens when people use inaccurate "knowledge"—**misconceptions**[5]—to elaborate? If people think that new information is clearly wrong within the context of what they currently believe about the world, they may ignore the information altogether. Alternatively, they may distort the information to be consistent with their "knowledge" and as a result learn something quite different from what they actually saw, heard, or read (P. K. Murphy & Mason, 2006; Porat, 2004; Sneider & Pulos, 1983; Vosniadou, 2008). In some instances, then, having *mis*information is more detrimental than having *no* information about a topic.

We saw one instance of such *mis*learning in Bartlett's (1932) study involving "The War of the Ghosts": Many students distorted the story to make it consistent with English culture. A study by Eaton, Anderson, and Smith (1984) provides another example. Fifth-graders spent several weeks studying a unit on light in their science curriculum. A pretest had shown that many students had a particular misconception about light: They believed that people see things only because the light shines on them and makes them brighter. During the unit, the correct explanation of human sight was presented: Light reflects off of objects and continues to travel *to the eye,* which then detects the light and makes vision possible. Despite reading and hearing this information, most students retained their misconceptions about vision in a test given at the end of the unit. Fewer than a third of them correctly indicated in their answers that light must travel not only from the light source to the object but also from the object to the eye.

Prior misconceptions can wreak havoc even at the college level (D. E. Brown & Hammer, 2008; Evans, 2008; Kendeou & van den Broek, 2005). For example, undergraduates who study the nature of vision in a psychology course—including the idea that light must travel from the object to the eye—often leave the course thinking that vision occurs because something travels in the *opposite* direction—that is, from the eye to the object (Winer, Cottrell, Gregg, Fournier, & Bica, 2002). Similarly, students in teacher education programs may disregard a professor's definitions for certain concepts—for instance, they may continue to think of *negative reinforcement* as a synonym for *punishment*—and they're apt to ignore research findings and recommended

[5]Some theorists prefer terms such as *naive beliefs* or *naive conceptions* to reflect the fact that such inaccuracies, although not a good match with contemporary scientific understandings, may be reasonable conclusions from a learner's early knowledge and experiences (e.g., see M. C. Linn & Eylon, 2011; Schneps & Sadler, 1989).

teaching practices that contradict their own beliefs about "good teaching" (Holt-Reynolds, 1992; V. Richardson, 2003; Tillema, 2000).

As we examine the nature of *personal theories* in Chapter 9, we'll look in greater depth at the kinds of misbeliefs children and adults are likely to have. And as we consider the topic of *conceptual change* later in that chapter, we'll identify possible strategies for replacing students' misconceptions with more productive understandings.

Expectations

For a simple exercise, quickly read the following lyrics from the popular song "Jingle Bells."

Dashing though the snow
In a one-house open sleigh
O'er the fields we go
Laughing all the way!
Bells on bohtail ring
Makng spirits bright
What fun it is to ride end sing
A sleighing song tonight!

You may have noticed one or two typographical errors in the lyrics. But did you catch them all? Altogether there were *five* mistakes: *though* in line 1, *house* in line 2, *bohtail* in line 5, *makng* in line 6, and *end* in line 7. If you didn't notice all the errors—and many people don't—then your expectation of what words *should* have been there influenced your perceptions. People often form expectations about the things they'll see and hear—expectations based on their existing knowledge and beliefs about how the world typically operates—and these can influence how they encode and store new information in long-term memory (Kaiser, McCloskey, & Proffitt, 1986; Schacter, 1999).

In many cases people perceive and learn something more quickly when they have a good idea ahead of time about the information they're going to receive, perhaps because relevant portions of long-term memory have already been activated (recall the discussion of *priming* in Chapter 7). For example, experienced readers tend not to look very carefully at what they're reading. Instead, they rely on such things as context, sentence syntax, prior knowledge, and expectations about what the author wants to communicate in order to draw conclusions about what's on the page (Dole, Duffy, Roehler, & Pearson, 1991; R. E. Owens, 1996; Pressley, 2002). Such an approach enables them to read more quickly and efficiently, but it has a potential drawback: They risk jumping to the *wrong* conclusions and misperceiving or misinterpreting what someone has written.

Earlier in the chapter I introduced the concept of *ambiguous stimulus,* a stimulus that can be interpreted in more than one way. Ambiguous stimuli are especially likely to be encoded in accordance with people's expectations (Eysenck & Keane, 1990; J. W. Sherman & Bessenoff, 1999). For instance, when I have shown the man–rat drawing (Figure 8.2) to students in my classes, I've consistently found that if I subtly create the expectation that I'll be showing a nonhuman animal—in particular, by first showing a drawing that's definitely a rodent—most students see a mouse or rat. But if I instead lead students to expect a person, most of them see the bald-headed man. And in the following verbal exchange, notice how your knowledge of social customs sets you up for an initial interpretation that's almost certainly incorrect (from Gleitman, 1985, p. 432):

"We're going to have my grandmother for Thanksgiving dinner."

"You are? Well, we're going to have turkey."

Many human behaviors are prime examples of ambiguous stimuli. For instance, if you see me smile at you (my behavior), you might draw any number of possible conclusions: Maybe I'm happy to see you, maybe I'm *not* happy to see you but I am being polite, maybe I detest you but need a favor, or maybe I think the shirt you're wearing looks ridiculous. People often interpret another person's behaviors in accordance with their beliefs about and expectations for that individual (Burgess, Wojslawowicz, Rubin, Rose-Krasnor, & Booth-LaForce, 2006; Crick & Dodge, 1996; Ritts, Patterson, & Tubbs, 1992; M. Snyder & Swann, 1978). They expect and so "see" desirable behaviors from someone they like or admire—a phenomenon known as the **halo effect**. In much the same way, they expect and so "see" inappropriate behaviors from a person they dislike—the **horns effect** in action.

Numerous factors affect people's expectations for—and hence their interpretations of—others' behaviors. For instance, people often expect higher-quality performance from someone who is clean and well groomed than from someone who is dirty and disheveled—hence the adage "Dress for success" (Darley & Gross, 1983). Teachers expect well-behaved students to be more academically successful than poorly behaved students, and their judgments of students' actual achievement levels are influenced accordingly (Bennett, Gottesman, Rock, & Cerullo, 1993). Stereotypes about people of different genders, races, ethnic backgrounds, and socioeconomic groups can also lead to certain expectations, sometimes for the better but often for the worse (Darley & Gross, 1983; C. Reyna, 2000; J. W. Sherman & Bessenoff, 1999; Stephan & Stephan, 2000).

Verbalization

An activity that clearly facilitates long-term memory storage is **verbalization**—talking or writing about an experience that either has previously happened or is currently happening. Children often talk with their parents or teachers about past and current events, and their memory for those events is enhanced as a result (Fivush, Haden, & Reese, 2006; McGuigan & Salmon, 2004; K. Nelson, 1996). For older children and adults, verbalization can also take the form of **self-explanation**, in which learners talk to themselves in an attempt to understand difficult subject matter. For example, when reading a challenging textbook, students might paraphrase the parts they understand, draw inferences from the ideas presented, and summarize what they've read. When students are encouraged to engage in overt self-explanation as they study something, they're more likely to elaborate on it and so better understand and remember the content (Eysink & de Jong, 2012; Fonseca & Chi, 2011; D. S. McNamara & Magliano, 2009; Renkl, 2011).

Writing provides yet another form of verbalization that can facilitate long-term memory storage. For instance, when students write about what they're reading in their textbooks—perhaps answering study questions, relating the material to things they already know, and analyzing various points of view—they're more likely to engage in such storage processes as meaningful learning, internal organization, and elaboration (S. L. Benton, 1997; R. E. Burnett & Kastman, 1997; S. Greene & Ackerman, 1995; T. Shanahan, 2004).

Enactment

By **enactment**, I mean engaging in an overt psychomotor behavior—actually *doing* something—that in some way reflects what's being learned. The importance of enactment has popped up in previous chapters under different guises: In our discussion of applications of behaviorist principles (Chapter 4), we noted the importance of *active responses* in learning, and in our discussion of social cognitive theory (Chapter 5), we noted the importance of *motor reproduction* in modeling.

A wide variety of physical actions seem to promote long-term memory storage. Young children can more easily remember a story when they can act it out with toy figures, and they can more easily remember geometric shapes when they can actually draw the shapes (A. M. Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004; Heindel & Kose, 1990). College students studying physics can better apply the things they learn about how pulley systems work when they can experiment with actual pulleys rather than when they simply look at diagrams of various pulley systems (Ferguson & Hegarty, 1995).

Physical enactment is especially helpful when people are learning complex motor skills—that is, when they're acquiring procedural knowledge. In such situations, people typically learn most effectively when they get regular feedback about how they're doing. Sometimes feedback comes from their own performance; for instance, they can see where and how far a ball goes when they hit it with a tennis racket or baseball bat. In other cases, they need feedback from a more advanced individual (e.g., a coach), who can offer suggestions on what they might do differently (Ennis & Chen, 2011; Proctor & Dutta, 1995; J. V. Stokes, Luiselli, & Reed, 2010).

In preceding chapters, we've noted that behaviorists think of feedback as a form of *positive reinforcement* (see Chapter 3) and that social cognitive theorists propose that feedback affects learners' *self-efficacy* (see Chapter 5). Here we see a third role that feedback can play: a source of *information* that can help learners improve their performance. Whenever possible, teachers should provide such information immediately so that students can store it in working memory simultaneously with their recollection of what they've just done; in this way, the two are more easily integrated (J. R. Anderson, 1987; Shute, 2008).

Repetition and Review

As you learned earlier in the chapter, rehearsal is usually a relatively *in*effective way to promote long-term memory storage. But in contrast to such short-lived rehearsal, reviewing and practicing information and procedures at periodic intervals over the course of a few weeks, months, or years clearly enhances memory and performance. This principle seems to hold true for people of all ages, even young infants (Finn & Roediger, 2011; Proctor & Dutta, 1995; Rohrer & Pashler, 2010; Rovee-Collier, 1993).

In essence, recent researchers have supported early verbal learning theorists' findings that *overlearning* facilitates memory. A second verbal learning principle is also relevant here: Additional learning and practice sessions are typically more effective when they're spaced over a period of time—that is, when they reflect *distributed practice* rather than *massed practice*. In the lingo of contemporary cognitive psychology, this phenomenon is known as the **spacing effect** (Dempster, 1991; Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Kornell, Castell, Eich, & Bjork, 2010; Pashler, Rohrer, Cepeda, & Carpenter, 2007).

It's important to note that learning is sometimes a bit *slower* when it's spread out over time. Its benefits are most clearly seen when we look at *long-term retention* rather than speed of initial learning (Dunlosky et al., 2013; M. C. Linn, 2008; Rawson & Kintsch, 2005). For example, in a study conducted on the Internet (Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008), adult volunteers who lived in various countries around the world studied a list of 32 obscure trivia facts, such as "What European nation consumes the most spicy Mexican food?" (p. 1097). The participants studied the list again in a study session that might be as little as 1 day to 4 months later. Finally, in a third session—which was delayed by as little as a week or as much as a year—they were tested on the facts. The longer the final test session was delayed, the longer was the optimal spacing of the two study sessions. If learners really want to remember information for the long haul, then, they should review it periodically at lengthy intervals (also see Pashler et al., 2007; Rohrer & Pashler, 2010). (In case you're curious, Norwegians are especially partial to spicy Mexican food.)

By reviewing and practicing what they've learned over a period of time, people probably accomplish several things. First, they engage in additional processing—processing that may allow them to elaborate on learned information in new ways and so understand it more thoroughly (Dempster, 1991; Karpicke, 2012; McDaniel & Masson, 1985). Second, by reviewing the same information repeatedly, especially in different contexts, they form more and stronger associations with other things in long-term memory; as a result, they can more readily recall the information when needed at a future time (J. R. Anderson, 2005; Calfee, 1981; Vaughn & Rawson, 2011). Continued practice seems to have a third benefit as well: It can promote automaticity.

Development of Automaticity

Cognitive psychologists distinguish between two general types of information processing: controlled and automatic (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). **Controlled processing** requires much of a person's attention and is likely to use most or all of the person's working memory capacity. For example, I still remember the summer evening many years ago when my father tried to teach me to drive using the standard transmission in our 1951 Ford convertible (no, I'm not *that* old; the car was almost an antique at the time). Trying to steer the car in the right direction while simultaneously monitoring the speed and negotiating the stick shift and clutch must have exceeded my working memory capacity, because I kept forgetting to step on the clutch, thus jerking the car forward and almost catapulting my father high into the air. (Dad enrolled me in a drivers' education class the following morning.)

In contrast, **automatic processing**—often called **automaticity**—occurs with little or no conscious attention or effort and requires little working memory capacity; it is, in a sense, "thoughtless." Controlled processes become increasingly automatic through repetition and practice (J. R. Anderson, 2005; Beilock & Carr, 2004; Cheng, 1985). As I continued to drive that 1951 Ford, I gradually became more proficient, and I was able to devote less and less mental effort to the task of driving. After several months of persistent practice, I was cruising Main Street with my friends, tapping my fingers to early Beatles music and scanning the sidewalk for male classmates of particular interest. Even though my car had a standard transmission, driving had essentially become an automatic activity for me.

Many academic tasks require performing a number of subtasks at more or less the same time. In order for these multi-subtask tasks not to overwhelm working memory, some of the subtasks must be automatic. Consider the case of reading. Comprehending what one reads is often a difficult task involving controlled, conscious effort. If learners are to understand what they read, basic reading processes such as letter and word identification must occur automatically (B. A. Greene & Royer, 1994; Klauda & Guthrie, 2008; Lervåg & Hulme, 2009; Walczyk et al., 2007). Good writing, too, is a multifaceted process that can easily exceed the limits of working memory unless basic spelling, grammar, and handwriting or keyboarding skills are automatic (Berninger, Fuller, & Whitaker, 1996; De La Paz & McCutchen, 2011; Graham, 2006; Limpo & Alves, 2013). And if students are to solve complex math problems successfully, some aspects of mathematics—especially basic math facts—need to become second nature (L. S. Fuchs et al., 2013; Hecht & Vagi, 2010; Mayer & Wittrock, 2006). I'm *not* saying here that learners should focus on automaticity at the expense of meaningful learning of basic knowledge and skills. Rather, learners should make sense of things *first* and then automatize the ones they'll subsequently need in complex tasks and problems.

Keep in mind that automaticity has downsides as well. For one thing, people may perform habitual actions without even thinking about them, to the point where they can't remember whether or not they've done them (Reason & Mycielska, 1982). A more serious disadvantage of automaticity is that it increases the chances that someone will quickly recall certain ideas or perform certain procedures when other, less automatic ideas or procedures would be more useful (Killeen, 2001; E. J. Langer, 2000; LeFevre, Bisanz, & Mrkonjic, 1988). People are far more flexible—and thus far more likely to identify unique approaches to situations or creative solutions to problems—when they aren't automatically locked into a particular response. We'll revisit this issue in the discussion of *mental set* in Chapter 13.

LONG-TERM MEMORY RETRIEVAL PROCESSES

We humans retrieve some information easily and effortlessly—in some cases without even trying—especially if we use the information fairly regularly (e.g., Berntsen, 2010; Hintzman, 2011). But we may struggle to recall certain things we haven't used for a while; the process can be slow and strenuous, and we won't necessarily "find" what we're looking for. For example, following are definitions of three words in the English language. Can you identify the specific words to which they refer?

- A picture form of writing used in ancient Egypt
- A hard-shelled, ocean-dwelling animal that attaches itself to rocks and ships
- A stiff, crunchy white substance often used in desserts; made from whipped egg whites and sugar

Did you find yourself mentally wandering around your long-term memory, looking in various "places" where a word might be located? Perhaps you even felt as if one of the words was *on the tip of your tongue.* Maybe you were pretty sure that one of the words began with a *B* and had three syllables, but you never did find it (A. Brown, 1991; R. Brown & McNeill, 1966; also see R. Thompson, Emmorey, & Gollan, 2005). (In case you couldn't retrieve all three words, they are *hieroglyphics, barnacle,* and *meringue*—pronounced "muh-rang." Of course, some of my readers may never have stored one or more of these words in the first place.)

Our ability to mentally and effortfully "look" for things in long-term memory depends partly on brain maturation (especially in the prefrontal cortex), and so it improves markedly over the course of infancy and early childhood (Oakes & Bauer, 2007). Even so, long-term memory is so large that an exhaustive inspection of it all is virtually impossible. Thus, we must be strategic in our retrieval efforts, looking in places where the desired information might logically be. And how successful we are in finding it depends to some extent on how we initially *stored* it—and in particular on whether we stored it in a thoughtful, well-organized manner.[6]

Let's take an example. Imagine a woman who has lived for the past 60 years in a house with an easily accessible attic; we'll call this woman "Granny." Granny has probably kept many things in her attic, including furniture, books, old clothes, seldom-used cooking utensils, and holiday decorations. Maybe she has been a very organized woman who has put all books in one spot, all clothes in another, and all holiday decorations somewhere else. Alternatively, maybe she has been throwing things up there any old place, so that some cooking utensils are with books, others are with clothes, and still others are stuffed in an old dresser or on the top shelf of a dilapidated armoire. How Granny has stored items in her attic undoubtedly affects her ability to find them later. If she has stored things systematically, she should be able to locate them easily when she needs them. But if she has stored them in a helter-skelter fashion, she may have to purchase new canning jars every summer because she can't track down her jars from any of the previous 13 years.

So it is with long-term memory. Retrieval is easier when related pieces of information are stored in close association with one another, because we then have a good idea about where to find a particular item. To illustrate, try answering this question about a concept presented in an earlier chapter:

What is a discriminative stimulus?

Your ability to retrieve the answer depends partly on how well you've organized what you've been learning from the book. The word *stimulus* should, of course, lead you to look among the things you've stored about behaviorist learning theories. The word *discriminative* might suggest to you that you look more specifically in your information about discrimination. If your knowledge about discrimination is stored with what you know about antecedent stimuli (and it should be, because the two concepts are related), then you should find the answer to the question. A discriminative stimulus lets you know that a particular response is likely to be reinforced; it *sets the occasion* for a particular response–reinforcement contingency to be in effect (see Chapter 3).

You might think of long-term memory retrieval as being similar to looking for something in a large, dark room with only a small flashlight (Lindsay & Norman, 1977). Imagine that the electricity goes off in Granny's house on a dark, moonless night. Because Granny can no longer use either her electric can opener or her electric lights, she takes a flashlight to the attic to find the manual can opener she put there last October. Unfortunately, the flashlight can't light up the whole attic at once. Instead, Granny must aim the light first at one spot, then at another, until eventually she finds the can opener. This should be easy if Granny knows the opener's logical location, but her efforts may be in vain if she has no idea where she might have put the thing. In much the same way, retrieval from long-term memory may be a process of looking in various

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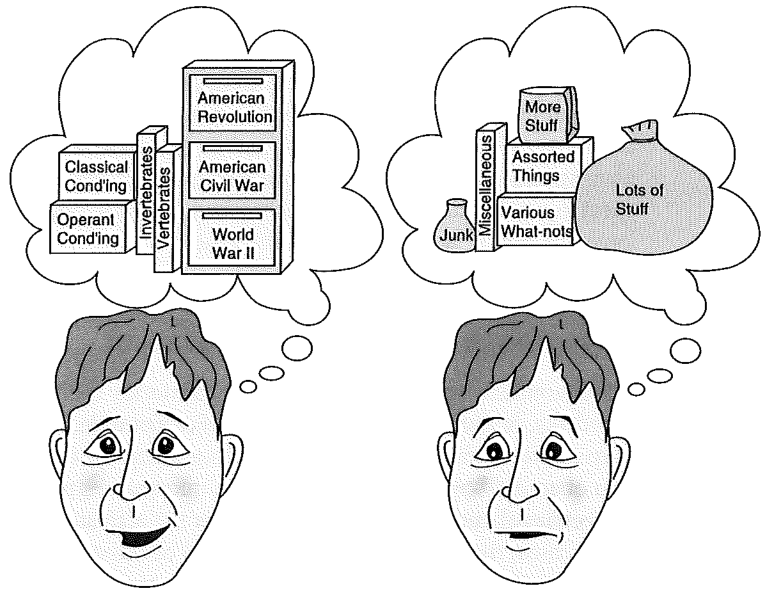
[6]Sometimes it's helpful to work with other people to jointly retrieve previously learned information. Such *collaborative recall* can often enhance our chances for remembering something we've previously learned, but in other cases one person's comments can steer other group members in the wrong directions in their long-term memory searches (e.g., see Rajaram & Pereira-Pasarin, 2010; Sutton, 2009).



An organized long-term memory makes things easier to retrieve.

small "locations" in memory, searching in only one location at a time. Information that's been stored in a logical place (i.e., associated with similar ideas) will probably be found quickly. Information that's been stored haphazardly, in a rote-learning fashion, will turn up only after a great deal of searching, if it turns up at all.

Let's return to the activation model of memory described in Chapter 7. According to this model, all information stored in memory is in either an active or an inactive state. Information in an active state is what we might think of as being in working memory, whereas inactive information is in long-term memory. The activation model lends itself particularly well to an understanding of how long-term memory retrieval might work. From this perspective, our starting point in long-term memory might be an idea triggered by something in the environment. Retrieval is then a process of **spreading activation**, with the activation flowing through connections within the network of stored information (e.g., J. R. Anderson et al., 2004; A. M. Collins & Loftus, 1975; Siegel, 2012). Only a small part of the network can be activated at once, thus accounting for the limited-capacity, "flashlight" quality of retrieval. If the activation eventually spreads to that part of the network in which the information is located—something that's more likely to happen if similar ideas are closely associated in the network—we'll find what we're looking for.

Let's also return to a point I made at the beginning of this section: We can retrieve some things easily and effortlessly—that is, with *automaticity*—especially if we use them frequently. If we look for certain bits of information fairly regularly, we may be continually traveling certain activation "pathways" in our long-term memory network, essentially "paving" them for faster travel and in some cases making them superhighways.

Furthermore, retrieval of information tends to be easier when learners engage in thought processes similar to those they previously used when storing the information—a phenomenon known as **encoding specificity** (Hanna & Remington, 1996; Tulving, 1983; Tulving & Thomson, 1973; Zeelenberg, 2005). For example, Marian and Neisser (2000) interviewed American college students who had immigrated to the United States from Russia or the Soviet Union and thus were fluent in both English and Russian. In two parts of the interview—one conducted in English, the other in Russian—the students were given certain words and asked to tell stories from their personal lives that the words called to mind. The interview language had a significant influence on the stories recalled: The students recalled more events from their birth country when they were speaking in Russian but more events from their time in the United States when they were speaking in English. Presumably they had, to some degree, *encoded* these personal events in the language they'd been speaking at the time.

Importance of Context for Retrieval

Some contexts seem to evoke certain memories (Balch, Bowman, & Mohler, 1992; Holland, Hendriks, & Aarts, 2005; Schab, 1990). For example, maybe the smell of freshly baked chocolate chip cookies reminds you of your childhood home, or maybe a certain song on the radio reminds you of an old boyfriend or girlfriend. In information processing lingo, these contexts are providing **retrieval cues**—hints that may trigger the activation of certain parts of long-term memory. In some cases, they may even trigger retrieval of classically conditioned responses (Bouton, 1994).

As an example of retrieval cues in action, try this exercise. Read the following list of 24 words *one time only.* I'll ask you to recall them as soon as you've finished.

tulip	pencil	spoon	bed	baker	ruby
hat	mountain	doctor	paper	daisy	shirt
chair	fork	diamond	canyon	knife	table
hill	soldier	rose	pen	shoe	emerald

Now that you've read all 24 words, cover the page and write as many of them as you can remember. *Don't look back at the list just yet.*

If you can't retrieve all 24, see if these words and phrases help you:

clothing	professions
eating utensils	writing supplies
gemstones	furniture
flowers	land forms

These category names should help you remember more of the words, because all 24 words fall into one of the categories.

As another example, if you've ever taken an introductory biology course, you've probably learned the traditional, multilevel classification system for categorizing plants and animals. Can you recall the names of the various category levels in their correct order? (Hint: One of them is *phylum.*) If you can't, maybe this sentence will help you in your retrieval efforts:

King Philip comes over for good spaghetti.

The first letters of the words in the sentence might trigger recall of *kingdom, phylum, class, order, family, genus,* and *species.* The sentence essentially serves as a *superimposed meaningful structure*, a type of mnemonic described in Chapter 12.

A downside of retrieval cues is that they occasionally set boundaries on the areas of long-term memory we search. For instance, in one study (J. Brown, 1968), an experimental group of college students was given a list of 25 U.S. states to read, while a control group had no such list. Both groups were then asked to recall as many of the 50 states as they could. Compared with the control group, the experimental group remembered more of the states they'd previously read but *fewer* of the states they *hadn't* read. Thus, retrieval cues can hinder recall when they direct a learner's search to parts of long-term memory *other* than those that hold desired information.

Construction in Retrieval

Like long-term memory storage, long-term memory retrieval can involve constructive processes. Often people retrieve only part of what they've previously stored, and they may fill in the holes based on what's logical or consistent with their existing knowledge and beliefs (Schacter, 2012). For example, recall the study by Carmichael and colleagues (1932) in which many participants' reproductions of line drawings were distorted in line with labels such as "eyeglasses" or "dumbbells" (see Figure 8.5); presumably, the participants were using the labels to fill in gaps in their recollections. In much the same way, people may mentally complete their partial recollections of crimes they've witnessed, perhaps based on their prior beliefs about the individuals involved. Eyewitness testimony isn't necessarily an accurate representation of what actually happened, even if the witness claims to be quite confident that such-and-such happened (Brainerd & Reyna, 2005; Loftus, 1991, 1992; Perfect, 2002; Wells, Olson, & Charman, 2002).

As another example of constructive processes in retrieval, consider what a fourth-grader in Michigan told a researcher about why the Americas were once called the New World:

> Because they used to live in England, the British, and they didn't know about . . . they wanted to get to China 'cause China had some things they wanted. They had some cups or whatever—no, they had furs. They had fur and stuff like that and they wanted to have a shorter way to get to China so they took it and they landed in Michigan, but it wasn't called Michigan. I think it was the British that landed in Michigan and they were there first and so they tried to claim that land, but it didn't work out for some reason so they took some furs and brought them back to Britain and they sold them, but they mostly wanted it for the furs. So then the English landed there and they claimed the land and they wanted to make it a state, and so they got it signed by the government or whoever, the big boss, then they were just starting to make it a state so the British just went up to the Upper Peninsula and they thought they could stay there for a little while. Then they had to fight a war, then the farmers, they were just volunteers, so the farmers went right back and tried to get their family put together back again. (VanSledright & Brophy, 1992, p. 849)

This student accurately recalled certain facts she had learned in history lessons at school. But she combined those facts with other "facts" she remembered incorrectly (e.g., early traders acquired furs in western North America rather than in China) and her general knowledge of the world (e.g., many cups are made of china). And she had apparently never learned one key idea: The "British" and the "English" were the same people. The result was a constructed account of Michigan's history that could give a historian heart failure.

Some memories, known as **flashbulb memories**, are so vivid and detailed that they have a seemingly "snapshot" quality to them; often these memories involve significant, emotion-laden events in one's personal life. Yet we shouldn't let the vividness mislead us: Some flashbulb memories are accurate, but others are not (Hirst et al., 2009; Talarico & Rubin, 2003; Winograd &

Neisser, 1992). As an example, an event in 1986 that became vivid in many Americans' minds was the explosion of the space shuttle *Challenger,* immediately plunging seven astronauts to their deaths. Neisser and Harsch (1992) asked American college students to describe how they learned of the crash on two different occasions: (a) the morning after the crash and (b) 2½ years later. Even after more than two years, many students were quite confident about their recollections. Despite their confidence, some of them were way off base. For instance, one student gave this account the morning after hearing about the disaster:

> I was in my religion class and some people walked in and started talking about [it]. I didn't know any details except that it had exploded and the schoolteacher's students had all been watching which I thought was so sad. Then after class I went to my room and watched the TV program talking about it and I got all the details from that. (Neisser & Harsch, 1992, p. 9)

The same student had this recollection 2½ years later:

> When I first heard about the explosion I was sitting in my freshman dorm room with my roommate and we were watching TV. It came on a news flash and we were both totally shocked. I was really upset and I went upstairs to talk to a friend of mine and then I called my parents. (Neisser & Harsch, 1992, p. 9)

Although constructive processes may be responsible for many errors in what we remember, usually they facilitate long-term memory retrieval. When our memory of something is incomplete, we can fill in details based on what makes sense. For example, if we're trying to remember how to spell the word *ascertain,* we might surmise that, because the word is related in meaning to the word *certain,* it should be spelled similarly even though it's pronounced quite differently. And if we're trying to recall who was prime minister of the United Kingdom at the end of World War II, we might think, "Hmm, Winston Churchill was a key figure in England around that time," and then conclude (correctly) that he was the prime minister.

The Power of Suggestion: Effects of Subsequently Presented Information

Sometimes people's recollections are influenced by information presented at some point *after* they learned whatever they're retrieving. Generally speaking, this is a good thing: People should continually update their knowledge and understandings as new information comes in. But in some situations, further information can be detrimental, especially if it's an incorrect statement, a misleading question, or some other deviation from reality (Fazio, Barber, Rajaram, Ornstein, & Marsh, 2013; G. S. Goodman & Quas, 2008; Loftus & Palmer, 1974; Zaragoza, Payment, Ackil, Drivdahl, & Beck, 2001). As an example, in a study with 3- to 6-year-old children (Leichtman & Ceci, 1995), a man identified as "Sam Stone" briefly visited a preschool classroom. Sam commented on the story the teacher was reading to the children, strolled around the perimeter of the room, waved goodbye, and left. Later, an adult asked, "When Sam Stone got that bear dirty, did he do it on purpose or as an accident?" and "Was Sam Stone happy or sad that he got the bear dirty?" (p. 571). When asked these questions, many of the children (especially the younger ones) recalled that Sam soiled a teddy bear, even though he never touched a stuffed animal during his visit.

The results just described illustrate the **misinformation effect**: People's memory for an event may become distorted when they subsequently receive inaccurate information about the event. Apparently, people integrate the new, misleading information with their original knowledge of the event in order to reconstruct what "must" have happened (Brainerd & Reyna, 2005; J. C. K. Chan, Thomas, & Bulevich, 2009; Loftus, 1992; Principe, Kanaya, Ceci, & Singh, 2006).

Constructing Entirely New "Memories" during Retrieval

In some cases, retrieval is almost entirely constructive in that people can produce information they've never specifically stored. For example, consider this arithmetic problem:

$\frac{1}{2} \times 0 = ?$

It's quite possible that you've never learned the answer to this particular problem, yet you no doubt learned long ago that anything times zero equals zero. Hence, you could construct the correct answer:

$\frac{1}{2} \times 0 = 0$

But some new "memories" are **false memories** that have little or no basis in fact (Brainerd & Reyna, 2005; Loftus, 2003, 2004). For example, asking people to picture an imaginary object or event increases the likelihood that, later on, they'll remember actually experiencing it; young children have an especially hard time distinguishing fact from fantasy (Foley, Harris, & Herman, 1994; Gonsalves et al., 2004; Mazzoni & Memon, 2003; J. Parker, 1995). And when people see photos of themselves partaking in a certain event—for instance, when an experimenter has electronically imposed their faces on photos of people taking a hot-air balloon ride—they may later recall actually participating in the event (Garry & Gerrie, 2005).

False memories are common when certain stimuli or events might reasonably or logically have been experienced. For example, in word-list learning tasks, people may "remember" seeing words that they never actually saw but that are close associates of words they *did* see, presumably because the unseen words were activated during the learning session (Brainerd & Reyna, 1998; Roediger & McDermott, 2000; Seamon, Luo, & Gallo, 1998; Urbach, Windmann, Payne, & Kutas, 2005). Plausibility also increases false recall of nonexperienced events, especially for older children and adults (D. M. Bernstein & Loftus, 2009; Ghetti & Alexander, 2004). For example, in one study (Pezdek, Finger, & Hodge, 1997), high school students were asked whether certain events had happened when they were 8 years old. Some of the events had actually happened, but the experimenters fabricated two others, one involving a common religious ritual for Catholic children and another involving a common ritual for Jewish children. As you might guess, Catholic students were more likely to "remember" the Catholic event, whereas Jewish students were more likely to "remember" the Jewish one, and their general knowledge about such events allowed them to "recall" numerous details about what had transpired.

Remembering Prior Recollections

In the study of memory about the *Challenger* crash described earlier (Neisser & Harsch, 1992), many students were interviewed a third time, three years after the disaster itself and thus six months after the second recall session. On this third occasion, most students essentially repeated their stories from six months before. When participants who inaccurately remembered the occasion were given hints about where they'd actually been and what they'd actually been doing, they stuck with their prior misrecollections; furthermore, they were quite surprised when they were shown their original, morning-after descriptions. It appeared that these students were remembering not what had actually happened but what they had previously *said* had happened.

In general, recalling an event we've previously experienced often affects our later memory for the event, especially if we verbally describe the event and perhaps embellish on it in some way (Karpicke, 2012; E. J. Marsh, 2007; Seligman, Railton, Baumeister, & Sripada, 2013). Neurologically speaking, by recalling the event, we're also revising and *reconsolidating* it in the brain—that is, we're firming it up anew (Finn & Roediger, 2011; Schiller et al., 2010). Author Marion Winik has poignantly described the process this way:

> Sometimes I think childhood memories are fabricated like pearls around a grain of sand. You know how it works: take one old photograph and the quick current of memory it sparks; add what you heard happened, what could have happened, what probably happened; then tell the story over and over until you get the details down. It doesn't take a degree in psychology to reverse-engineer your childhood based on the adult it produced.
>
> Even if I've made it all up, it doesn't matter. I'm stuck with the past I believe in, even if it's wrong. (Winik, 1994, p. 40)

Teachers, clinicians, law-enforcement officers, attorneys, and other individuals who rely on people's memories to conduct their work must continually keep in mind the constructive nature of long-term memory retrieval. Often human memories are reasonably accurate. But as we've seen, they can occasionally be badly distorted or even completely fabricated.

FORGETTING

One thing about long-term memory is certainly clear: Over time, people recall less and less about specific events they've experienced and specific information they've acquired. Theorists have offered a number of explanations about why we forget a good deal of what we've learned.

Decay

Increasingly, psychologists have come to believe that information can gradually fade away, or **decay**, especially if it's rarely or never used (Altmann & Gray, 2002; Byrnes, 2001; Loftus & Loftus, 1980; Schacter, 1999). Typically, the exact details of an event fade more quickly than its underlying meaning, or gist (Brainerd & Reyna, 1992, 2002, 2005; G. Cohen, 2000). We find an exception to this general rule when certain details are surprising, personally significant, or in some other way quite distinctive (Davachi & Dobbins, 2008; Hunt & Worthen, 2006; Pansky & Koriat, 2004). For example, when I think back to my early lessons in U.S. history, I can recall the general idea behind the American Revolution: The colonists were fighting for independence from British rule. I also remember two specific details about the revolution: The Battle of Bunker Hill is commemorated by a monument I visited as a child, and the Boston Tea Party was a unique and colorful illustration of the colonists' dissatisfaction with British taxation policies. But I've forgotten many other details I learned in those early lessons, because, to my young mind, they involved unknown, nondistinctive people and places.

Interference and Inhibition

In Chapter 6, I described verbal learning theorists' concepts of proactive and retroactive inhibition: In both situations, learning one set of verbal information interferes with the ability to recall another set and thus can be a major cause of forgetting. Some contemporary memory theorists agree, although they often use the term **interference** rather than inhibition (e.g., Altmann & Gray, 2002; M. C. Anderson, 2009a; Healey, Campbell, Hasher, & Ossher, 2010; Lustig, Konkel, & Jacoby, 2004).

An interference view of forgetting might best be described as a theory of confusion: A person has learned numerous responses and gets them mixed up. An experiment by John Anderson (1974) helps us place interference within a contemporary cognitive framework. College students learned a long list of single-proposition sentences, each of which involved a person and a place; here are some examples:

A hippie is in the park.

A hippie is in the church.

A policeman is in the park.

A sailor is in the park.

Some people and places appeared in only one sentence, whereas others appeared in several sentences. The students studied the sentences until they could correctly answer a long list of questions (e.g., "Where are the hippies?" "Who is in the park?"). At that point, they were given a new set of sentences and asked to indicate whether each sentence had been in the original set. The more frequently a person and place had appeared in the earlier sentences, the longer it took students to determine whether the person and place had previously been *together* in a sentence. Anderson explained these results by suggesting that if a particular concept was associated with several other concepts—for instance, if *hippie* was associated with several different locations—a person would have to search among all those associations in order to determine the "newness" or "oldness" of a sentence in the second set. Thus, multiple associations with a concept can sometimes slow down retrieval time for specific information connected with the concept—a phenomenon that Anderson has called the **fan effect** (e.g., J. R. Anderson, 1983a; J. R. Anderson et al., 2004).

Now let's return to the term *inhibition,* this time putting it within a contemporary cognitive framework. Although retrieving one memory usually facilitates retrieval of related memories (again recall the discussion of *priming* in Chapter 7), in some instances related memories are inhibited—a process known as **retrieval-induced forgetting** (Bäuml & Samenieh, 2010; M. D. MacLeod & Saunders, 2008; Román, Soriano, Gómez-Ariza, & Bajo, 2009; Storm, 2011). In particular, a learner may intentionally want to recall certain things but *not* to recall certain other, related things and thus learns to inhibit recall of those other things. For example, imagine that you think the capital of Turkey is its largest and best-known city: Istanbul. But Turkey's capital is actually a very different city: Ankara. If for some reason you needed to remember the capital of Turkey, you'd have to both retrieve "Ankara" *and* inhibit your inclination to retrieve "Istanbul"—something you might learn to do, especially with some practice.

Repression

In the earlier discussion of flashbulb memories, you learned that some emotionally laden events result in especially vivid, detailed recollections. In other situations, however, people may have an experience that's so painful or emotionally distressing that they tend either not to remember it at all or else to remember only isolated fragments (Arrigo & Pezdek, 1997; Nadel & Jacobs, 1998; Ray et al., 2006). This phenomenon, often called **repression**,[7] was first described by Sigmund Freud (1915/1957, 1922). To explain repression from a contemporary memory theory framework, painful information can evoke enough tension and anxiety that the individual steers clear of it when searching long-term memory. The information hasn't disappeared; it just isn't consciously retrieved (M. C. Anderson & Levy, 2009; S. M. Smith & Moynan, 2008).

Repression is occasionally observed in clinical settings (Pezdek & Banks, 1996; Schooler, 2001). Over a series of therapy sessions, perhaps with the help of hypnosis (which induces relaxation), a client gradually recalls bits and pieces of a traumatic incident and may eventually remember the entire event. Unfortunately, many presumably repressed "memories" are never checked for accuracy; thus, they may or may not be based on something that actually occurred (Geraerts et al., 2009; Loftus, 1993; McNally, 2003). For instance, although a hypnotic state may increase people's confidence and willingness to talk about past events, it doesn't necessarily improve their memory for what transpired (Brainerd & Reyna, 2005; Dinges et al., 1992; Erdelyi, 2010; Lynn, Lock, Myers, & Payne, 1997).

When true repression occurs—and sometimes it really does—it's probably a form of inhibition: People either consciously or unconsciously try *not* to recall a highly anxiety-arousing, traumatic event (M. C. Anderson & Green, 2001; M. C. Anderson & Levy, 2009; Ray et al., 2006).[8] However, it appears that most people don't repress painful information as a matter of course (Berntsen, 2010; G. S. Goodman et al., 2003; S. Porter & Peace, 2007).

Failure to Retrieve

You can probably think of occasions when you couldn't remember something at first but then recalled it later on. Using the flashlight analogy again, we might say that **failure to retrieve** occurs when people neglect to "look" in the part of long-term memory that holds the desired information. Perhaps the information was initially stored in connection with ideas very different from those one is thinking about at the present time. Or perhaps the information was stored with very few connections to other ideas; as a result, even a broad search of memory doesn't focus the activation "flashlight" on it.

Some instances of failure to retrieve involve forgetting to do something that needs to be done at a future time—a problem of **prospective memory** (Einstein & McDaniel, 2005; S. A. Stokes, Pierroutsakos, & Einstein, 2007). For example, when I was a young college professor, I often forgot to turn off my car lights after driving to work on a foggy morning. And occasionally I'd forget to bring crucial handouts or other needed materials to class. It's not that I would lose information from my long-term memory. When I went to the parking lot at the end of the day and discovered my dead car battery, I would readily remember that I had turned on my car lights that morning. When I eventually realized that I'd forgotten to bring important handouts to class—usually this occurred at the point in the class session where I needed them—I knew perfectly well that they were part of my lesson plan. My problem was that I *forgot to retrieve* important information at the appropriate time.

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[7]An alternative term is *psychogenic amnesia,* which describes the nature of the phenomenon without offering the "repression" explanation of why it occurs (Arrigo & Pezdek, 1997).

[8]When people consciously and deliberately try not to remember something, the terms *suppression* and *motivated forgetting* are often used instead of *repression* (e.g., M. C. Anderson, 2009b).

I've since found that the best way to address this forgetting-to-retrieve problem is to create an **external retrieval cue**—a physical reminder outside of (external to) the memory system. For example, over the years I've developed several techniques that have made me one of the *least* absentminded people on the planet. I use my cell phone calendar to record not only the meetings and appointments I need to go to but also the things I do regularly every week, and I preset loud *alerts* in the calendar for must-do commitments I might forget about on the days I need to do them. I write notes to myself about things I need to do on a particular day or accomplish by the end of the week, and I put them in plain sight on my desk. And if I need to be sure to bring something with me when I go somewhere, I put it on the floor between my desk and my office door, so that I'll definitely see it as I leave. Essentially, what I'm doing is guaranteeing retrieval of the things I need to remember.

Construction Error

We've already seen how construction can lead to errors in recall. Construction errors can occur either during storage (i.e., learner-invented information is stored) or at retrieval (i.e., the learner "remembers" information that was never encountered). Construction at retrieval time is especially likely when the retrieved information has holes in it—holes possibly due to decay, interference, or unsuccessful retrieval. Thus, as you might expect, erroneous reconstruction of previously acquired information is increasingly common as time goes on (Bergman & Roediger, 1999; Brainerd & Reyna, 2005; Dooling & Christiaansen, 1977).

Insufficient Self-Monitoring during Retrieval

In Chapter 5, you read about an aspect of self-regulation known as *self-monitoring,* in which people observe and assess their own behaviors. It appears that people may also engage in self-monitoring of a more cognitive nature when they retrieve information from long-term memory. In particular, they reflect on their recollections in an effort to determine whether they're remembering something accurately or inaccurately (Koriat & Goldsmith, 1996). For instance, people are more likely to believe a recollection is accurate when it's plausible—when it's consistent with what they know about themselves and about the world in general. They're also more likely to have confidence in the accuracy of a memory when it's vivid, detailed, and easy to retrieve—perhaps when it seems to "jump out" at them from long-term memory. And because they know that their memories of long-ago events are typically rather hazy, they'll often agree that non-recalled events in early childhood—including some that a researcher has made up—probably happened. Consistent with what you'll learn about *metacognition* in Chapter 12, the ability to take such factors into account when self-monitoring the accuracy of memories improves over the course of childhood (Ghetti, 2008; Ghetti & Alexander, 2004; Mazzoni & Kirsch, 2002; Mazzoni, Scoboria, & Harvey, 2010).

Failure to Store or Consolidate

A final explanation of "forgetting" is the fact that some information may never have been completely stored in the first place. Perhaps a learner didn't pay attention to the information, so it never entered working memory. Or perhaps the learner didn't process it sufficiently to get it into long-term memory. Even if it *did* get into long-term memory, perhaps some outside factor—maybe a serious head injury—interfered with consolidation processes (see Chapter 2).

In some instances, the brain may store information only in ways that lead to implicit knowledge, which isn't accessible to *conscious* retrieval. This is probably the best explanation of why people remember little or nothing about events that occurred before age 3 (Nadel, 2005; C. A. Nelson, 1995; Newcombe, Drummey, Fox, Lie, & Ottinger-Albergs, 2000). Psychologists have offered at least two plausible explanations for this phenomenon of **infantile amnesia**. First, brain structures that are actively involved in explicit memories, such as the hippocampus and frontal cortex, aren't fully developed at birth, and the frontal cortex in particular continues to mature in significant ways for several years thereafter (C. A. Nelson, Thomas, & de Haan, 2006; Newcombe et al., 2000; Oakes & Bauer, 2007). Second, talking about experiences enhances memory for them, as you learned in an earlier section about *verbalization*, but small children have only limited language skills with which to discuss events with others.

All the explanations just presented are probably partially responsible for the universal human problem of forgetting. Yet forgetting isn't necessarily a bad thing. Many of the things we learn have little use to us later on (especially *much* later), and we rarely need to remember things exactly as we originally experienced them. In fact, saving every scrap of information we've ever acquired—you might think of this as *mental hoarding*—would probably make retrieval of things we *do* need extremely difficult (J. R. Anderson & Schooler, 1991; Ratey, 2001; Schacter, 1999). Think once again about Granny's attic: What shape would it be in if she saved every single object she'd ever laid her hands on?

Promoting Effective Long-Term Memory Storage and Retrieval Processes

I often hear educators making the distinction between teacher-centered and learner-centered approaches to instruction. By *teacher-centered instruction,* they mean methods in which the instructor directly presents the material to be learned—for instance, through lectures, textbooks, and videos. Because teacher-centered methods often present information in essentially the same form that students are expected to learn it, they're sometimes called **expository instruction**. In contrast, *learner-centered instruction* encourages students to construct their *own* knowledge and understandings, although usually within the context of planned activities and some degree of teacher guidance. Discovery learning, whole-class and small-group discussions, cooperative learning, and group problem-solving activities are all examples of learner-centered instruction.

In my opinion, the terms *teacher-centered* and *learner-centered* are misnomers. Presumably students are at the center of *any* form of instruction, in that teachers design their lessons with students' learning—rather than their own learning—in mind. The key difference isn't one of focus but rather one of *control:* Students direct the course of learning to a greater degree in learner-centered approaches than in teacher-centered approaches. Hence, I suggest that we use different terminology. In **teacher-directed instruction**, the teacher calls most of the shots, choosing what topics will be addressed and determining the course of the lesson. In **learner-directed instruction**, students have considerable say in the issues they address and how to address them.

In recent decades, educators and educational psychologists have vigorously debated the pros and cons of teacher-directed versus learner-directed methods of instruction (e.g., Chall, 2000;

Tobias & Duffy, 2009a). Yet we're really talking about a *continuum* of directedness here—not an either–or dichotomy—and various degrees of teacher directedness are appropriate in different situations (e.g., Baer & Garrett, 2010; Spiro & DeSchryver, 2009). Ultimately, what matters most about any instructional method is not whether it's teacher- or learner-directed but *how well it promotes effective storage and retrieval processes*. Following are general principles that should guide instructional practices regardless of whether they're teacher-directed or learner-directed in nature.

◆ *Instruction is more effective when it activates and builds on students' prior knowledge.* Even when students have existing knowledge to which they can relate new material, they aren't always aware of connections they might make. Thus, effective instruction includes **prior knowledge activation**: It begins with what students already know and continues to remind students of additional things they know that relate to the topic at hand. For example, teachers and students might discuss a topic in class before students begin a reading assignment about it (Baer & Garrett, 2010; Hansen & Pearson, 1983; P. T. Wilson & Anderson, 1986). And when content studied at a previous time is important for understanding something new, teachers might provide a quick refresher of that content.

If students have virtually *no* prior knowledge about a topic, teachers might provide actual experiences on which subsequent instruction can build. Consider, for example, the idea of *taxation without representation*—a policy that greatly distressed American colonists in the pre-Revolution 1700s. Many adults can easily relate the idea of taxation without representation to their own frustrations with high taxes, but most fifth-graders have little or no experience on which to build an understanding of the colonists' situation. To help students empathize with the colonists' circumstances, a teacher might conduct an activity in which students are told to give valued objects to fellow students (only temporarily) without regard for their own wishes in the matter. I often use this create-an-experience strategy myself, not only in my classes but also in my books; asking you to read "The War of the Ghosts" earlier in the chapter was an example. I then follow up by relating new concepts and principles to the experience my students or readers have just had.

Another effective strategy is to provide analogies that relate classroom subject matter to familiar concepts and situations (Bulgren, Deshler, Schumaker, & Lenz, 2000; Donnelly & McDaniel, 1993; Pinker, 2007; Zook, 1991). For example, earlier in this chapter I compared long-term memory retrieval to *looking for something in a large, dark room with only a small flashlight.* Here are three other examples:

- If we think of the Earth's history as a *24-hour day,* human beings have been in existence only for the last minute of that day (Hartmann, Miller, & Lee, 1984).
- The growth of a glacier is like *pancake batter being poured into a frying pan.* As more and more substance is added to the middle, the edges spread farther and farther out (courtesy of R. K. Ormrod).
- Peristalsis, a process that moves food through the digestive system, is like *squeezing ketchup out of a small packet at a fast-food restaurant.* You begin by squeezing the packet at one end and then gradually move your fingers across the packet to push the ketchup out at the other end (Newby, Ertmer, & Stepich, 1994).

◆ *Students are more likely to engage in meaningful learning when they're explicitly encouraged to do so.* Students must approach new information with the attitude that they can understand and make sense of it. In other words, they must approach it with a **meaningful learning set** (Ausubel et al., 1978; M. A. Church, Elliot, & Gable, 2001; Kintsch, 2009). Students are more likely to have this attitude when teachers emphasize understanding rather than verbatim recitation—for instance, when students know they'll be expected to explain concepts in their own words rather than reproduce textbook definitions. But ultimately, students must have confidence that they *can* understand new material. Students who've learned through past experience that certain kinds of subject matter are confusing or incomprehensible are more likely to resort to a rote-learning approach (Ausubel & Robinson, 1969; Bandalos et al., 2003; D. E. Brown & Hammer, 2008).

◆ *Instruction is more effective when it helps students organize new material.* One widely recommended strategy is to provide an **advance organizer**, a general introduction to new material that's typically designed either to provide an overview of upcoming ideas or to show students how the material relates to students' previous knowledge and experiences (Ausubel et al., 1978). Research consistently demonstrates the effectiveness of advance organizers in facilitating learning, especially when material isn't clearly organized and students have trouble organizing and making sense of it on their own (L. Alexander, Frankiewicz, & Williams, 1979; Corkill, 1992; Mayer, 1984; Naumann, Richter, Flender, Christmann, & Groeben, 2007). A variety of formats—introductory paragraphs, outlines, analogies, examples, and thought-provoking questions—can be effective, especially when they're fairly concrete. In some situations, an advance organizer might take a graphic rather than strictly verbal form. For example, I'm hoping that Figure 7.1 served as an advance organizer for you as you were reading about various components of human memory in Chapter 7.

Once expository instruction is well underway, it should ideally present new information in the basic organizational format in which students should store it in memory (Dansereau, 1995; Niederhauser, 2008; Wade, 1992). For example, teachers facilitate students' learning when they present ideas in a logical sequence, identify hierarchical relationships that exist among concepts, and make cause-and-effect relationships clear. Showing how material should be organized and interconnected may be especially important for students with little relevant background knowledge or a history of learning difficulties (deLeeuw & Chi, 2003; Krajcik, 1991; Mayer, 2010a; Niederhauser, 2008).

Yet another effective strategy is a **concept map** or **knowledge map**—a diagram of a unit's concepts or main ideas (often identified by circles) and the interrelationships among them (often designated by lines and by words or phrases that link two concepts or ideas together). As an illustration, Figure 8.7 presents a concept map that a teacher might use to organize key concepts in a lesson on ancient Egyptian art. But students, too, can be shown how to construct concept maps that help them organize what they're learning. Both teacher- and student-constructed organizational maps have often been shown to facilitate learning, provided that they're not *so* detailed that they overwhelm students' working memory capacities (Hofman & van Oostendorp, 1999; Novak, 1998; O'Donnell, Dansereau, & Hall, 2002; Stull & Mayer, 2007).

◆ *Instruction is more effective when it encourages students to elaborate on what they're learning.* Many classroom activities can potentially promote student elaboration of classroom subject matter. For example, having students talk about a topic, perhaps within the context of a class discussion, small-group problem-solving task, or peer tutoring activity, almost forces them to mentally *do* something with the material (more on these strategies in Chapter 11). And simply asking questions that require students to draw inferences from what they're learning can be extremely productive (Brophy, Alleman, & Knighton, 2009; Croninger & Valli, 2009; J. A. Langer, 2011; McCrudden & Schraw, 2007).

In the discussion of instructional goals and objectives in Chapter 4, we made a distinction between lower-level skills and higher-level skills; this is essentially a distinction between simply

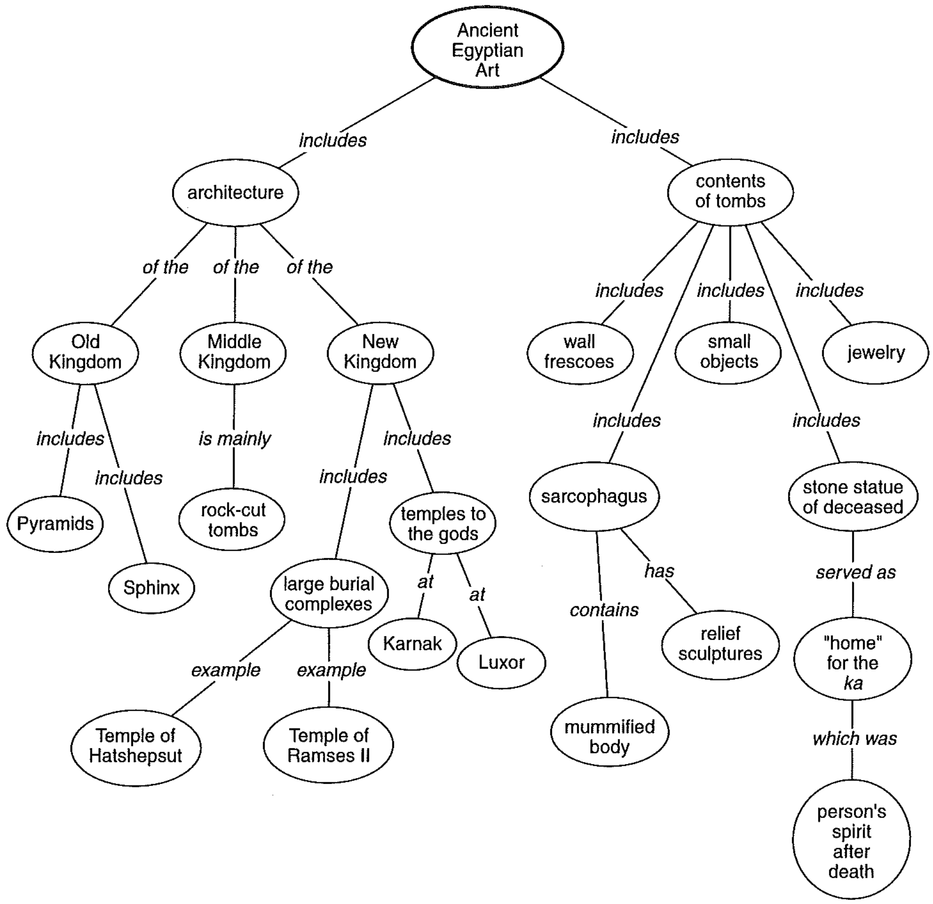

Figure 8.7
A possible concept map for a lesson on ancient Egyptian art.

knowing something versus *doing* something (mentally) with that knowledge—for instance, applying, analyzing, synthesizing, or evaluating it. We can make a parallel distinction between **lower-level questions** and **higher-level questions**: The former ask students to retrieve something pretty much as they've stored it in memory, whereas the latter encourage students to elaborate on what they've learned and enhance their understanding. For instance, following is something a middle school science teacher in Colorado might ask. As you read it, be aware that the altitude of Rocky Mountain National Park ranges from 1½ to more than 2 miles above sea level.

> A group of Girl Scouts went hiking in Rocky Mountain National Park. They noticed that it was harder to breathe when hiking in the mountains than when hiking in [hometown]. During the hike, one girl opened a tube of suntan lotion that she bought in [hometown]. When she opened it, a small squirt of air and lotion shot out.
>
> - Why did the girls have a hard time breathing?
> - Why did the air and lotion squirt out of the tube? (Pugh, Schmidt, & Russell, 2010, p. 9)

Teachers should keep in mind, however, that it's unreasonable to expect students to formulate insightful, creative responses to higher-level questions in a split second. Students need time both to retrieve what they've previously learned and to think about how they might use this information in a new context. When teachers build reasonable **wait times** into their lessons—perhaps by allowing several seconds of silence to elapse after a thought-provoking question—more students participate in class, and students are more likely to support their reasoning with evidence or logic and more likely to speculate when they don't know an answer (Castagno & Brayboy, 2008; Moon, 2008; Rowe, 1974, 1987; Tobin, 1987). My own teaching experiences suggest that giving students some wait time after asking a question indirectly communicates to them that answering the question won't necessarily be *easy* and that there isn't necessarily a single right answer. I subtly communicate these messages in another way as well: by having a puzzled, *Hmm-what-do-you-think?* expression on my face as I pose the question.

Teachers must remember, too, that elaboration can sometimes lead students to acquire inaccurate ideas, especially if the students already have misconceptions about the topic at hand. Thus, teachers should continually monitor students' understanding of classroom material—perhaps by asking questions, assigning regular homework, or giving occasional quizzes—and then take steps to correct any misinterpretations that students' responses reveal. Some of their misconceptions may be stubborn ones that aren't easily corrected; we'll identify strategies for changing such misconceptions in the section on *conceptual change* in Chapter 9.

◆ *Visual aids enhance long-term memory storage.* As we've seen, visual imagery can be a highly effective way of encoding information and may be especially valuable when used in conjunction with such other storage processes as meaningful learning or elaboration. Thus, presenting information in visual form—perhaps through concrete objects, live models, pictures, maps, computer-based animations, or educational videos[9]—can often be a helpful supplement to verbal material, provided that the combination doesn't impose too much of a cognitive load on students as they're studying new material (Butcher, 2006; Carney & Levin, 2002; Mayer, 2010a; Schneps et al., 2014; Verdi & Kulhavy, 2002). In some instances, visuals can actually *reduce* the strain on working memory—apparently because they provide an external, outside-of-working-memory means of storing some of the information a learner is trying to make sense of (Butcher, 2006; R. Carlson, Chandler, & Sweller, 2003; Plass, Kalyuga, & Leutner, 2010). In addition to promoting visual imagery, many visual aids help students see how major ideas relate to and affect one another; thus, they provide one more way of helping students organize information (Levin & Mayer, 1993; Winn, 1991).

Also effective is having students create their *own* illustrations of concepts and principles they're studying. For example, students might show how the nervous system works by drawing a diagram of a neuron, or they might illustrate gravity, friction, and kinetic energy using a picture of a roller coaster (Edens & Potter, 2001; Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010; van der Veen, 2012; Van Meter, 2001).

◆ *The most effective ways to teach procedural knowledge depend to some degree on the nature of the procedures to be learned.* When a new skill is almost entirely a behavioral one, with little

[9]One excellent source of educational videos is Khan Academy (www.khanacademy.org), which offers free online videos on a wide variety of academic topics.

or no cognitive involvement, then picture illustrations, live demonstrations, verbal rehearsal of the steps involved, and practice with immediate feedback can all be quite effective (Shute, 2008; SooHoo et al., 2004; J. V. Stokes, Luiselli, & Reed, 2010; Vintere, Hemmes, Brown, & Poulson, 2004; Zimmerman & Kitsantas, 1999). Also helpful is videotaping the learner in action, with subsequent analysis and feedback regarding the strengths and weaknesses of the performance (Bear, Torgerson, & Dubois-Gerchak, 2010; Prater, Carter, Hitchcock, & Dowrick, 2011; J. V. Stokes, Luiselli, Reed, & Fleming, 2010).

Additional strategies are called for when procedures and skills involve considerable mental work, as is true for solving math problems, repairing car engines, and playing a strategic game of basketball. In such circumstances, instruction about procedures must go hand in hand with instruction that helps students understand why the procedures make sense—that is, procedural knowledge and declarative knowledge should be learned in tandem. For example, the instructor might verbalize his or her own thoughts—thereby demonstrating *mental* procedures and their rationales—while engaging in the task (recall the discussion of *cognitive modeling* in Chapter 5). Similarly, students can be asked to explain what they're doing and why they're doing it as they practice (deLeeuw & Chi, 2003; Dominowski, 1998). When procedures are fairly complex and multifaceted, teachers may want to break them down into smaller tasks and have students practice each one separately at first (J. R. Anderson, Reder, & Simon, 1996; Beilock & Carr, 2004; van Merriënboer & Kester, 2008).

Chapter 12 and Chapter 13 describe more strategies for facilitating the acquisition of procedural knowledge, especially procedures related to metacognition and problem solving, respectively.

◆ *Information that must be retrieved within a particular context should ideally be stored within that context.* People are most likely to retrieve information relevant to a situation when they've stored that information in close association with other aspects of the situation. Accordingly, teachers should give students numerous opportunities to relate classroom material to the various activities that are later likely to require its retrieval. For example, students are more likely to retrieve mathematical ideas relevant to accounting, surveying, or engineering if their math teacher incorporates problems involving accounting, surveying, and engineering into instruction. Similarly, students who are studying for a psychology test that stresses application will be better prepared if they spend some time considering various scenarios in which psychological principles might be applied. Furthermore, students should have opportunities to use the things they learn in real-world contexts; we'll consider such *authentic activities* in Chapter 11 and Chapter 13.

◆ *Taxonomies of goals and objectives can be useful reminders of the various ways in which students might be asked to think about and apply what they've learned.* In the discussion of instructional goals and objectives in Chapter 4, we looked at Bloom's early Taxonomy of Educational Objectives, which suggests six increasingly complex levels of behavior that teachers might encourage and assess (B. S. Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). More recently, a collaborative group of educational psychologists (L. W. Anderson et al., 2001) revised the taxonomy, in part to reflect theoretical advances in learning and cognition. The revision is a two-dimensional taxonomy that includes six *cognitive processes,* each of which is potentially relevant to four different *types of knowledge* (see Figure 8.8). The six cognitive processes are similar to the six levels in Bloom's original taxonomy (look once again at Figure 4.5). However, the cognitive processes

L. W. Anderson and colleagues' (2001) revision of Bloom's Taxonomy includes six *cognitive processes,* each of which is potentially relevant to four different *types of knowledge.*

Cognitive Processes

1. **Remember:** recognizing or recalling information learned at an earlier time and stored in long-term memory
2. **Understand:** constructing meaning from instructional materials and messages (e.g., drawing inferences, identifying new examples, summarizing)
3. **Apply:** using knowledge in a familiar or new situation
4. **Analyze:** breaking information into its constituent parts, and perhaps identifying interrelationships among those parts
5. **Evaluate:** making judgments about information using certain criteria or standards
6. **Create:** putting knowledge and/or procedures together to form a coherent, structured, and possibly original whole

Types of Knowledge

A. **Factual knowledge:** knowing specific pieces of information (e.g., facts, terminology)
B. **Conceptual knowledge:** knowing more general structures and interrelationships among pieces of information (e.g., general principles, schemas, models, theories)
C. **Procedural knowledge:** knowing how to do something (e.g., using step-by-step algorithms, employing scientific research methods), and possibly applying certain criteria in choosing the procedure to use
D. **Metacognitive knowledge:** knowing about the nature of thinking and about effective learning strategies, and being aware of one's own cognitive processes

Figure 8.8
A two-dimensional revision of Bloom's Taxonomy (L. W. Anderson et al., 2001).

are described by verbs rather than nouns, and the last two, *evaluate* and *create,* reflect a reversal of Bloom's *synthesis* and *evaluation* levels. The four types of knowledge include two forms of declarative knowledge, *factual knowledge* and *conceptual knowledge,* as well as *procedural knowledge* and *metacognitive knowledge* (we'll look at the nature of the last one more closely in Chapter 12).

The two dimensions of the revised taxonomy are intended to represent two continuums that progress from very simple cognitive processes and types of knowledge to more complex ones. The continuums aren't hard and fast, however; for example, some forms of conceptual knowledge can be fairly complex and abstract, whereas some forms of procedural knowledge are quite simple and concrete (L. W. Anderson et al., 2001; Marzano & Kendall, 2007). Rather than nitpick about the extent to which certain cognitive processes or types of knowledge are truly more complex than others, a more useful perspective of the revised taxonomy is to regard it as a helpful reminder of the various kinds of knowledge that students might have and the various ways in which they might learn and elaborate on it and then use it in new situations.[10]

◆ *Rapid learning doesn't necessarily mean better learning.* Earlier in the chapter, we noted that distributed practice sometimes leads to slower learning than massed practice but tends to

[10]Another useful taxonomy is Marzano and Kendall's (2007) New Taxonomy, which also includes attitudes and emotions and distinguishes among various *levels of processing.* It's detailed enough that I can't really do it justice in a book such as this one.

promote greater retention of material over the long run. More generally, the speed with which students learn something isn't necessarily a good indication of how *well* they learn it (Phye, 2001; Rohrer & Pashler, 2010; R. A. Schmidt & Bjork, 1992; D. L. Schwartz, Lindgren, & Lewis, 2009). To truly master a topic, students must relate it to things they already know, form many interconnections among its various parts, draw inferences about and in other ways elaborate on it, and perhaps learn certain parts to automaticity. Such things take time—in some cases a great deal of time—but for important topics and skills, it's time well spent.

Furthermore, although some feedback is essential for effective learning to occur, sometimes occasional rather than continual feedback about one's performance can promote performance over the long run, even if it initially results in slower improvement (R. A. Schmidt & Bjork, 1992). It may be that learners need practice not only in performing certain tasks but also in retrieving relevant knowledge about each task and giving *themselves* feedback about their performance (R. A. Schmidt & Bjork, 1992; Shute, 2008). And when learners make errors along the way—and especially when they're given guidance about how to *detect* and *correct* their errors—they become more comfortable with occasional mistakes and perform better over the long haul (Keith & Frese, 2005; Mathan & Koedinger, 2005).

◆ *Effective instruction provides opportunities for review and practice of previously learned knowledge and skills.* As we've seen, rehearsal of information within a short time span (e.g., less than a minute) isn't terribly effective as a way of storing information in long-term memory. But occasional repetition of learned information over a longer period of time—for instance, over the course of a few days, weeks, or months—*does* enhance storage and retention. Thus, teachers should have students review and practice important material throughout the school year, perhaps by occasionally asking questions about material addressed in earlier lessons, incorporating the material into the context of new lessons, or having students practice using it in educational video games (e.g., S. K. Carpenter, Pashler, & Cepeda, 2009; McDaniel, Anderson, Derbish, & Morrisette, 2007; Plass et al., 2013). Repetition is especially important for facts and skills that students need every day—basic number facts, spellings of commonly used words, punctuation rules, and the like. These facts and skills should certainly be learned as meaningfully as possible, but they should also be practiced until students can retrieve them with some degree of automaticity.

Another good strategy is to provide a summary at the end of a lesson or written passage (J. Hartley & Trueman, 1982; Lorch, Lorch, & Inman, 1993; Naumann et al., 2007). Summaries probably serve several functions: They can help students (a) review material, (b) determine which of the many ideas presented are most important to focus on, and (c) pull key ideas into a more cohesive organizational structure.

◆ *Classroom assessment practices significantly affect both storage and retrieval.* In Chapter 4, you encountered the distinction between formative assessment and summative assessment. Formative assessments, summative assessments, or both, can—*when appropriately designed*—enhance students' learning and memory in several ways:

- *By promoting productive storage processes.* Students tend to read and study differently depending on how they expect their learning to be assessed

(J. R. Frederiksen & Collins, 1989; Lundeberg & Fox, 1991; Quelmalz et al., 2013). For example, students are likely to focus on memorizing isolated facts in a rote fashion if they think that an upcoming assessment will require verbatim recall. They're more likely to try to make sense of and elaborate on what they're studying if they know they'll have to apply, analyze, or synthesize what they've learned. One effective way of instilling the latter expectation is to create and share a two-dimensional scoring *rubric* for one or more assessments that includes higher-level thinking skills (Arter & Chappuis, 2006; Panadero & Jonsson, 2013). You can find an example in the writing rubric presented in Figure 4.7 in Chapter 4: With the exception of the rubric's first row ("correct spelling"), the desired characteristics involve some ability to apply or in other ways elaborate on previously learned knowledge and skills.

- *By encouraging review before the assessment.* Preparing for assessments is one way of reviewing classroom material (Glass & Sinha, 2013; Halpin & Halpin, 1982; McDaniel, Agarwal, Huelser, McDermott, & Roediger, 2011). For instance, most students study new material more thoroughly and learn it better when they're told they'll be tested on it than when they're simply told to learn it. We should note, however, that students typically spend more time studying the information they think will be on an assessment than the things they think an assessment won't cover (J. R. Frederiksen & Collins, 1989; N. Frederiksen, 1984b).
- *By requiring review during the assessment itself.* Taking a test or completing an assignment is, in and of itself, an occasion for retrieving and reviewing learned information. Generally speaking, the very process of completing an assessment on classroom material helps students learn the material better (Dempster, 1991; Roediger & Karpicke, 2006; Rohrer & Pashler, 2010; Zaromb & Roediger, 2010). But once again, the nature of the assessment probably makes a difference here. For example, tasks that require students to write about what they've learned (e.g., short-answer questions) lead to better recall than tasks that require only recognition of facts (e.g., multiple-choice questions) (A. C. Butler & Roediger, 2007; S. H. K. Kang, McDermott, & Roediger, 2007). And tasks that require students to go beyond the material itself (e.g., to draw inferences) are more likely to be effective than those that ask only for recall of previously learned information (Chappuis, 2009; Foos & Fisher, 1988).
- *By providing feedback.* Assessments provide a concrete mechanism for letting students know what things they've learned correctly and what things they've learned either incorrectly or not at all. For example, when students get constructive comments on their essays—comments that point out the strengths and weaknesses of each response, indicate where answers are ambiguous or imprecise, and suggest how an essay might be more complete or better organized—their understanding of class material and their writing skills are both likely to improve (J. B. Baron, 1987; P. Black & Wiliam, 1998; Hattie & Timperley, 2007; Krampen, 1987; Shute, 2008).

When we look at typical classroom achievement tests, we're apt to see test items that focus largely on lower-level skills—such as knowledge of simple facts—possibly because such items are the easiest ones to write (J. R. Frederiksen & Collins, 1989; J. P. Gee, 2010; Newstead, 2004; Poole, 1994; Silver & Kenney, 1995). If teachers want students to do *more* than memorize facts, they must develop assessment tasks that encourage students to process information in certain ways—perhaps to rephrase ideas in their own words, generate their own examples of concepts, relate principles and procedures to real-world situations, use class material to solve problems, or examine ideas with a critical eye. Sometimes well-constructed test items can encourage such processes; for instance, in the exams I've created for my own classes, I've tried to use questions and tasks that require students to elaborate on what they've studied, often by asking them to recognize new examples of concepts they've learned or to evaluate various instructional strategies using principles of learning and memory. In many cases, however, teachers may want to use other kinds of assessment activities—perhaps writing stories, collecting and synthesizing data, comparing contradictory historical accounts, critiquing government policies, creating portfolios—that more readily allow students to apply classroom subject matter to new problems and situations, including those in their own lives (DiMartino & Castaneda, 2007; R. L. Johnson, Penny, & Gordon, 2009; R. S. Johnson, Mims-Cox, & Doyle-Nichols, 2006; L. Shepard, Hammerness, Darling-Hammond, & Rust, 2005).

SUMMARY

Many psychologists believe that long-term memory storage processes can be very constructive in nature—that people combine the incomplete data they get from their environment with things they've previously learned to construct logical understandings of new stimuli and events. Possibly some information is stored through simple *rehearsal*—verbally repeating it over and over in a relatively mindless fashion—but many theorists have questioned rehearsal's effectiveness for remembering something for any significant length of time. Certain other cognitive processes seem to yield more enduring declarative knowledge. *Meaningful learning* is connecting new material with similar ideas already stored in memory. *Internal organization* is the integration of various pieces of new information into a cohesive, interrelated whole. *Elaboration* involves embellishing on new information using one's previously acquired knowledge and beliefs. And *visual imagery* is encoding information in a mental "picture" of sorts that captures some of its physical appearance. Such storage processes may also play a role in the acquisition of procedural knowledge (e.g., motor skills, problem-solving strategies), in part because declarative knowledge can support learners' efforts in the early stages of acquiring a new skill.

Several cognitive factors affect long-term memory storage. Learners are likely to relate new material to their existing knowledge only when both things are in working memory at the same time. A greater amount of existing knowledge about a topic—provided that it's *accurate*—usually facilitates long-term memory storage; however, erroneous ideas and expectations can lead to distortions in what's learned and remembered. Overt behaviors can affect long-term memory storage as well. For instance, it's often helpful to talk about, write about, or physically enact aspects of the information and skills being learned, and occasional repetition of information and skills stretched out over a long time period can make them easier to remember in the long run. Basic facts and skills needed on a regular basis should be practiced over and over until they're learned to a level of *automaticity*—that is, until they can be retrieved and used quickly and effortlessly.

Retrieval from long-term memory appears to be a process of searching its contents, in one mental "location" at a time, until the desired knowledge is found. Retrieval is easier when information has previously been stored in connection with many other ideas in memory, when it's been learned to automaticity, or when relevant *retrieval cues* are present. Retrieval is often a constructive process: Some pieces of information are directly retrieved, but—for better or for worse—other details may need to be filled in based on one's previous knowledge and beliefs about the event or topic at hand. People sometimes "remember" things they've never specifically learned, perhaps because they draw reasonable inferences from what they *have* learned or perhaps because related ideas in long-term memory were activated during the initial learning experience. Describing a previous event in a particular way increases the likelihood that people will remember it in the same way on future occasions; in a sense, they remember their previous *recollections* of an event as much as (or even more than) they remember the event itself.

Theorists have offered a variety of explanations for why people "forget" things they've presumably learned, including decay, interference, inhibition, repression, failure to retrieve, construction error, insufficient self-monitoring, and failure to completely store or consolidate information. Forgetting isn't necessarily a bad thing: People typically have little use for the trivial details of everyday life, and they rarely need to remember important information word for word.

Contemporary psychologists have made a distinction between teacher-centered and learner-centered instruction, but the two approaches might better be described as *teacher-directed* versus *learner-directed* instruction. Although some theorists have argued that one approach is better than the other, in fact the effectiveness of either approach depends on the cognitive processes it encourages students to engage in. Regardless of the specific instructional methods used, teachers can foster effective long-term memory storage and retrieval processes in a variety of ways—for example, by activating students' prior knowledge about a topic, helping students organize and integrate new material, encouraging students to draw inferences and in other ways elaborate on ideas, and providing many opportunities for practice and review. Classroom assessment practices, too, should encourage effective storage and retrieval processes by focusing on things that students must ultimately be able to do with the knowledge and skills they acquire—for instance, to apply these things to new situations and problems.