Chapter 2

How the Brain Processes Information

There are probably more differences in human brains than in any other animal partly because the human brain does most of its developing in the outside world.

—Robert Ornstein and Richard Thompson,
The Amazing Brain

Chapter Highlights: This chapter presents a modern dynamic model of how the brain deals with information from the senses. It covers the behavior of the two temporary memories, the criteria for long-term storage, and the impact of the self-concept on learning.

Although the brain remains largely a mystery beyond its own understanding, we are slowly uncovering more about its baffling processes. Using scanning technologies, researchers can display in vivid color the differences in brain cell metabolism that occur in response to different types of brain work. A computer constructs a color-coded map indicating what different areas are doing during such activities as learning new words, analyzing tones, doing mathematical calculations, or responding to images. One thing is clear: The brain calls selected areas into play depending on what the individual is doing at the moment. This knowledge encourages us to construct models that explain data and behavior, but models are useful only when they contain some predictability about specific operations. In choosing a model, it is necessary to select those specific operations that can be meaningfully depicted and represented in a way that is consistent with more recent research findings.

THE INFORMATION PROCESSING MODEL

Several models exist to explain brain behavior. In designing a model for this book, I needed one that would accurately represent the complex research of neuroscientists in such a way as to be understood by educational practitioners. I recognize that a model is just one person's view of reality, and I readily admit that this particular information processing model comes closest to *my* view of how the brain learns. It differs from other models in that it escapes the limits of the computer metaphor and recognizes that learning, storing, and remembering are dynamic and interactive processes. Beyond that, the model incorporates much of the recent findings of research and is sufficiently flexible to adjust to new findings as they are revealed. I have already made several changes in this model since I began working with it nearly 30 years ago. A few additional changes are the result of new information learned since the third edition of this book was published. My hope is that classroom teachers will be encouraged to reflect on their methodology and decide if there are new insights here that could affect their instruction and improve learning.

Origins of the Model

The precursor of this model was developed by Robert Stahl (1985) of Arizona State University in the early 1980s. Stahl's more complex model synthesized the research in the 1960s and 1970s on cognitive processing and learning. His goal was to convince teacher educators that they should use his model to help prospective teachers understand how and why learning occurs. He also used the model to develop an elaborate and fascinating learning taxonomy designed to promote higher-order thinking skills. Certain components of the model needed to be altered as a result of subsequent discoveries in neuroscience.

Usefulness of the Model

The model discussed here (Figure 2.1) has been updated so that it can be used by the widest range of teacher educators and practitioners. It uses common objects to represent various stages in the process. Even this revised model does not pretend to include all the ways that researchers believe the human brain deals with information, thought, and behavior. It limits its scope to the major cerebral operations that deal with the collecting, evaluating, storing, and retrieving of information—the parts most useful to educators.

The model starts with information from our environment and shows how the senses reject or accept it for further processing. It then explains the two temporary memories, how they operate, and the factors that determine if a learning is likely to be stored. Finally, it shows the inescapable impact that experiences and self-concept have on future learning. The model is simple, but the processes are extraordinarily complex. Knowing how the human brain seems to process information and learn can help teachers plan lessons that students are more likely to understand and remember.

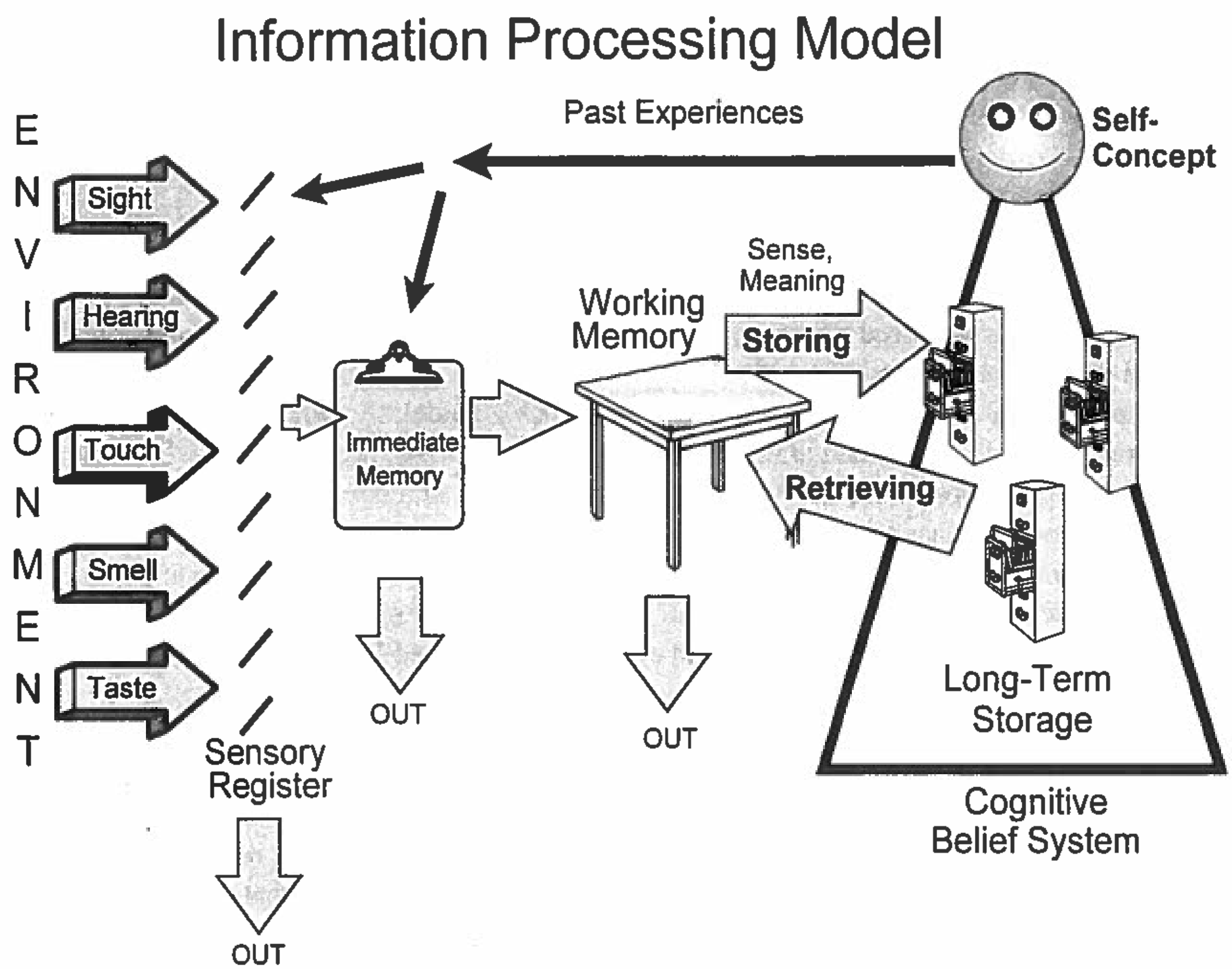

Figure 2.1 The Information Processing Model represents a simplified explanation of how the brain deals with information from the environment. Information from the senses passes through the sensory register to immediate memory and then on to working memory for conscious processing. If the learner attaches sense and meaning to the learning, it is likely to be stored. The self-concept often determines how much attention the learner will give to new information.

Limitations of the Model

Although the explanation of the model will follow items going through the processing system, it is important to note that this linear approach is used solely for simplicity and clarity. Much of the recent evidence on memory supports a model of parallel processing. That is, many items are processed quickly and simultaneously (within limits), taking different paths through and out of the system. Memories are dynamic and dispersed, and the brain has the capacity to change its own properties as the result of experience. Even though the model may seem to represent learning and remembering as a mechanistic process, it must be remembered that we are describing a *biological process*. Nonetheless, I have avoided

> ***The brain changes its own properties as a result of experience.***

a detailed discussion of the biochemical changes that occur within and between neurons. That would not contribute to the understanding necessary to convert the fruits of research and this model into successful classroom practice, which is, after all, our goal.

Inadequacy of the Computer Model

The rapid proliferation of computers has encouraged the use of the computer model to explain brain functions. This is indeed tempting, especially as computers become more complex and more integrated into various components of society. Using the analogy of input, processing, and output seems so natural, but there are serious problems with such a model. Certainly, the smallest handheld calculator can out-tally the human brain in solving complex mathematical operations. More powerful computers can play chess, translate one language into another, and correct massive manuscripts for most spelling and grammatical errors in just seconds. The brain performs more slowly because of the time it takes for a nerve impulse to travel along the axon, because of synaptic delays, and because the capacity of its working memory is limited. But computers cannot exercise judgment with the ease of the human brain. Even the most sophisticated computers are closed linear systems limited to binary code, the 0s and 1s in linear sequences that are the language of computer operations.

The human brain has no such limitations. It is an open, parallel-processing system continually interacting with the physical and social worlds outside. It analyzes, integrates, and synthesizes information and abstracts generalities from it. Each neuron is alive and altered by its experiences and its environment. As you read these words, neurons are interacting with each other, reforming and dissolving storage sites, and establishing different electrical patterns that correspond to your new learning.

How the brain stores information is also very different from a computer. The brain stores sequences of patterns, and recalling just one piece of a pattern can activate the whole. We can also identify the same thing in different forms, such as recognizing our best friend from behind or by her walk or voice. Computers cannot deal well with such variations (Hawkins & Blakeslee, 2004). Moreover, emotions play an important role in human processing, comprehension, and creativity. And the ideas generated by the human brain often come from images, not from logical propositions. For these and many other reasons, the computer model is at this time, in my opinion, inadequate and misleading. Of course, it is possible that sometime in the not-too-distant future, computers will be able to mimic many of the qualities, capabilities, and weaknesses possessed by the human brain.

As you read these words, neurons in your brain are interacting with each other in patterns that correspond to your new learning.

At first glance, the model may seem to perpetuate the traditional approach to teaching and learning—that students repeat newly learned information in quizzes, tests, and reports. On the contrary, the new research is revealing that students are more likely to gain greater understanding of and derive greater pleasure from learning when allowed to *transform* the learning into creative thoughts and products. This model emphasizes the power of transfer during learning and the importance of moving students through higher levels of complexity of thought. This will be explained further in Chapters 4 and 5.

The Senses

Our brain takes in more information from our environment in a single day than the largest computer does in a year. That information is detected by our five senses. (Note: Apart from the five classical senses of sight, hearing, smell, touch, and taste, our body has special sensory receptors that detect internal signals. For example, we have receptors inside the ear and body muscles that detect the body's movement and position in space; sensory hairs in the ear that detect balance and gravity; stretch receptors in muscles that help the brain coordinate muscular contraction; and pain receptors throughout the body. For the purposes of the model, however, I have focused on the classical senses because they are the major receptors of *external* stimuli used by the brain to acquire information and skills.)

All sensory stimuli enter the brain as a stream of electrical impulses that result from neurons firing in sequence along the specific sensory pathways. The brain sits in a black box (the skull) and does not see light waves or hear sound waves. Rather, certain specialized modules of neurons process the electrical impulses created by the light and sound waves into what the brain *perceives* as vision and sound.

The senses do not all contribute equally to our learning. Over the course of our lives, sight, hearing, and touch (including kinesthetic experiences) contribute the most. Our senses constantly collect tens of thousands of bits of information from the environment every second, even while we sleep. That number may seem very high, but think about it. The nerve endings on your skin are detecting the clothes you are wearing. Your ears pick up sounds around you, the rods and cones in your eyes are reacting to this print as they move across the page, you may still be tasting recent food or drink, and your nose may be detecting an odor. Put these data together and you see how they can add up. Of course, the stimuli must be strong enough for the senses to detect and record them.

Sensory Register

Imagine if the brain had to give its full attention to all those bits of data at once. We would blow the cerebral equivalent of a fuse! Fortunately, the brain has evolved a system for screening all these data to determine their importance to the individual. This system involves the *thalamus* (located in the limbic system) and a portion of the brain stem known as the *reticular activating system* (RAS). This system, which is also referred to as the *sensory register*, is drawn in the model as the side view of venetian blind slats (see the slashes in Figure 2.1). Like the blinds, the sensory register filters incoming information to determine how important it is.

All incoming sensory information (except smell, which goes directly to the amygdala and other destinations) is sent first to the thalamus, which briefly monitors the strength and nature of the sensory impulses for survival content and, in just milliseconds (a millisecond is one one-thousandth of a second), uses the individual's past experiences to determine the data's degree of importance. Most of the data signals are unimportant, so the sensory register allows them to drop out of the processing system. Have you ever noticed how you can be in a room studying while there is construction noise outside? Eventually, it seems that you no longer hear the noise. Your sensory register is blocking these repetitive stimuli, allowing your conscious brain to focus on more important things. This process is called *perceptual* or *sensory filtering*, and, to a large degree, we are consciously unaware of it.

The sensory register does hold sensory information for a very brief time (usually less than a second). This is referred to as *sensory memory*. Let's say you are intently watching a football game during the final minutes of play. Your spouse comes in and starts talking about an important matter. After a few minutes, your spouse says, "You're not listening to me!" Without batting an eye you say, "Yes, I am," and then proceed to repeat your spouse's last sentence word for word. Fortunately, you captured this sensory memory trace just before it decayed, and nipped a potential argument in the bud.

Short-Term Memory

As researchers gain greater insight into the brain's memory processes, they have had to devise and revise terms that describe the various stages of memory. *Short-term memory* is used by cognitive neuroscientists to include all of the early steps of temporary memory that will lead to stable long-term memory. Short-term memory primarily includes *immediate memory* and *working memory* (Cowan, 2009; Gazzaniga, Ivry, & Mangun, 2002; Squire & Kandel, 1999).

You cannot recall information that your brain does not retain.

Immediate Memory

Sensory data that are not lost move from the thalamus to the sensory processing areas of the cortex and through the first of two temporary memories, now called *immediate memory*. The idea that we seem to have two temporary memories is a way of explaining how the brain deals with large amounts of sensory data, and how we can continue to process these stimuli subconsciously for many seconds beyond the sensory register's time limits. Indeed, some neuroscientists equate sensory memory and immediate memory, arguing that separating them is more a convenience than a biological necessity.

For our purposes, we will represent immediate memory in the model as a clipboard, a place where we put information briefly until we make a decision on how to dispose of it. Immediate memory operates subconsciously or consciously and holds data for up to about 30 seconds. (Note: The numbers used in this chapter are averages over time. There are always exceptions to these values as a result of human variations or pathologies.) The individual's experiences determine its importance. If the item is of little or no importance within this time frame, it drops out of the system. For example, when you look up the telephone number of the local pizza parlor, you usually can remember it just long enough to make the call. After that, the number is of no further importance and drops out of immediate memory. Later on, you will have little success in remembering the entire number because you cannot recall information that your brain does not retain.

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Examples of Immediate Memory at Work. Here are two other examples to understand how the processing occurs up to this point. Suppose you decide to wear a new pair of shoes to work today. They are snug, so when you put them on, the receptors in your skin send pain impulses to the sensory register. For a short time you feel discomfort. After a while, however, as you get involved with work, you do not notice the discomfort signals anymore. The sensory register is now blocking the impulses from reaching your consciousness. Should you move your foot in a way that causes the shoe to pinch, however, the sensory register will pass this pain stimulus along to your consciousness, and you will become aware of it once again.

Another example: You are sitting in a classroom, and a police car with its siren wailing passes by. Experience reminds you that a siren is an important sound. Signals from the sensory register pass the auditory stimuli over to immediate memory. If over the next few seconds the sound of the siren gets fainter, experience signals the immediate memory that the sound is of no further importance, and the auditory data are blocked and dropped from the system. All this is happening subconsciously while your attention is focused on something else. If asked about the sound 15 minutes later, you will not remember it. You cannot recall what you have not stored.

Suppose, on the other hand, that the siren sound gets louder and suddenly stops, followed by another siren that gets louder and stops. Experience will now signal that the sounds are important because they are nearby, may affect your survival, and therefore require your attention. At this point, the now-important auditory data move rapidly into working memory for conscious processing so that you can decide what action to take.

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Threats and Emotions Affect Memory Processing. This last example illustrates another characteristic of brain processing: There is a hierarchy of response to sensory input (Figure 2.2). Any input that is of higher priority diminishes the processing of data of lower priority. The brain's main job is to help its owner survive. Thus, it will process immediately any data interpreted as posing a threat to the survival of the individual, such as a burning odor, a snarling dog, or someone threatening bodily injury. Upon receiving the stimulus, the reticular activating system sends a rush of adrenaline throughout the brain. This reflexive response shuts down all unnecessary activity and directs the brain's attention to the source of the stimulus.

Emotional data also take high priority. When an individual responds emotionally to a situation, the older limbic system (stimulated by the amygdala) takes a major role, and the complex cerebral processes are suspended. We have all had experiences when anger, fear of the unknown, or joy quickly overcame our rational thoughts. This reflexive override of conscious thought can be strong enough to cause temporary inability to talk ("I was dumbfounded") or move ("I froze"). This happens because the hippocampus is susceptible to stress hormones that can inhibit cognitive functioning and long-term memory.

Under certain conditions, emotions can enhance memory by causing the release of hormones that stimulate the amygdala to signal brain regions to strengthen memory. Strong emotions can shut down conscious processing during the event while enhancing our memory of it. Emotion is a powerful and misunderstood force in learning and memory. Another way of stating the hierarchy illustrated in Figure 2.2 is that before students will turn their attention to cognitive learning (the curriculum), they must feel physically safe and emotionally secure in the school environment.

Over the years, most teacher-training classes have told prospective teachers to focus on reason, cover the curriculum, and avoid emotions in their lessons. Now, we need to enlighten educators about how emotions consistently affect attention and learning. Districts must ensure that schools are free of weapons and violence. Teachers can then promote emotional security in the classroom

Students must feel physically safe and emotionally secure before they can focus on the curriculum.

How a person "feels" about a learning situation determines the amount of attention devoted to it.

by establishing a positive climate that encourages students to take appropriate risks. Students must sense that the teacher wants to help them be right rather than catch them being wrong.

Moreover, superintendents and board members need to examine their actions, which set the emotional climate of a district. Is it a place where people want to come to work? Does the district reward or frown on appropriate risk taking?

How a person "feels" about a learning situation determines the amount of attention devoted to it. Emotions interact with reason to support or inhibit learning. To be successful learners and productive citizens, we need to know how to use our emotions intelligently. Thus, we need to explore what and how we teach students about their emotions. For example, we could teach about controlling impulses, delaying gratification, expressing feelings, managing relationships, and reducing stress. Students should recognize that they can manage their emotions for greater productivity and can develop emotional skills for greater success in life.

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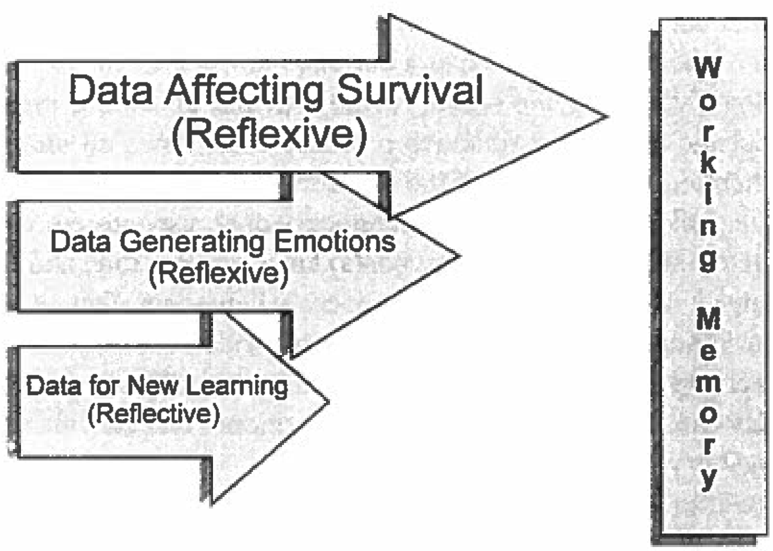

Figure 2.2 Data affecting survival and data generating emotions are processed ahead of data for new learning, which in school is called curriculum.

Working Memory

Working memory is also a temporary memory and the place where conscious, rather than subconscious, processing occurs. The information processing model represents working memory as a work table, a place of limited capacity where we can build, take apart, or rework ideas for eventual storage somewhere else. When something is in working memory, it generally captures our focus and demands our attention. Information in working memory can come from the sensory/immediate memories or be retrieved from long-term memory. Brain imaging studies show that most of working memory's activity occurs in the frontal lobes, although other parts of the brain are often called into action.

In recent years, researchers have compiled studies suggesting that the functioning of working memory can be explained by a three-part system (Figure 2.3) containing a *central control* (executive) *mechanism* and two subordinate components involved in rehearsal (Baddeley, 2003; Gazzaniga et al., 2002). The central control mechanism manages the interactions between the two subordinate systems and long-term memory. The *phonological loop* is the mechanism that uses auditory signals to code information into working memory, such as when we are talking about what we are learning. The *visuospatial sketchpad* allows for encoding information into working memory in solely visual or as a combination of visual and spatial (visuospatial) codes. This three-part model suggests that auditory and visual rehearsal *occurring during learning* increase working memory's interactions with long-term memory, raising the probability it will be stored.

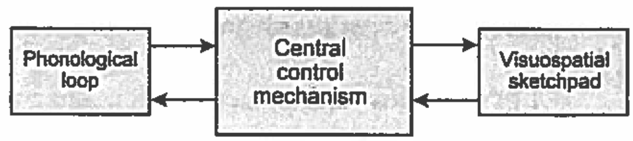

Figure 2.3 This model represents the three-part system that composes working memory. The central control mechanism manages the phonological loop and the visuospatial sketchpad (Baddeley, 2003).

There is also experimental evidence that when working memory is processing new information, the visuospatial component can become so activated that it has difficulty filtering out nonrelated images (de Fockert, Rees, Frith, & Lavie, 2001). This finding could have implications for cellular phone use in cars. If the phone conversation requires sufficient thought processing, it may sufficiently stimulate working memory so that the driver becomes distracted by irrelevant sights along the road.

Capacity of Working Memory. Miller (1956) discovered years ago that working memory can handle only a few items at once. The capacity of working memory appears to be decreasing for reasons we do not yet understand (see Table 2.1). Not surprisingly, this functional capacity changes with age in that children have a smaller capacity than adolescents and adults (Cowan et al., 2010; Gilchrist, Cowan, & Naveh-Benjamin, 2009). Preschool infants can deal with about two items of information at once. Preadolescents can handle three to seven items, with an average of five. Through adolescence, further cognitive expansion occurs, and the capacity increases to a range of five to nine, with an average of seven. For most people, that number remains constant throughout life.

More recent research has raised questions about the exact capacity limit of working memory. Some studies suggest that it now may be three to five chunks for adults. A few others say it is difficult to state an actual number because variables such as interest, mental time delays, and distractions may undermine and invalidate experimental attempts to find a capacity limit (Cowan, 2010). Nonetheless, most of the research evidence to date supports the notion that working memory has a functional limit and that the actual number varies with the learner's age and the type of input (factual information, visual, etc).

Table 2.1 Changes in Capacity of Working Memory With Age		
Approximate Age Range in Years	**Capacity of Working Memory in Number of Chunks**	
	Minimum	**Maximum**
Younger Than 5	1	2
Between 5 and Adolescence	3	4
Adults	3	5

Let's test this notion. Get a pencil and a piece of paper. When ready, stare at the number below for five seconds, then look away and write it down. Ready? Go.

92170

Check the number you wrote down. Chances are you got it right. Let's try it again with the same rules. Stare at the number below for five seconds, then look away and write it down. Ready? Go.

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Again, check the number you wrote down. Did you get all 10 of the digits in the correct sequence? Probably not. Because the digits were random, you had to treat each digit as a single item, and your working memory just ran out of functional capacity.

This limited capacity explains why we have to memorize a song or a poem in stages. We start with the first group of lines by repeating them frequently (a process called *rehearsal*). Then we memorize the next lines and repeat them with the first group, and so on. It is possible to increase the number of items within the functional capacity of working memory through a process called *chunking*. This process will be explained more fully in the next chapter.

Why would such a sophisticated structure like the human brain exhibit such severe limitations in working memory capacity? No one knows for sure. One possible explanation is that it is unlikely during the development of the brain thousands of years ago that our ancestors had to process or identify more than one thing at a time. It is also unlikely that they had to make several split-second decisions at the same time. Even in fight-or-flight situations, there probably was only one enemy or predator at a time. Today, however, people are often trying to do several things at once during their workday, making the memory's capacity limits more obvious.

We should not look upon these capacity limitations necessarily as a weakness. Having a relatively small number of items in working memory may allow the items to become more easily associated with each other—that is, chunked—without causing confusion. From one point of view, this could be a distinct cognitive advantage, especially for children. We should also note that, although we have several items in working memory simultaneously, we can focus on only *one* item at a time (Oberauer & Bialkova, 2009).

Implications for Teaching. Can you see the implication this functional capacity has on lesson planning? It means that the elementary teacher who expects students to remember in one lesson the eight rules for using the comma is already in trouble. So is the high school or college teacher who wants students to learn in one lesson the names and locations of the 10 most important rivers in the world. Keeping the number of items in a lesson objective within the appropriate capacity limit increases the likelihood that students will remember more of what they learned. Less is more!

> ***Keep the number of items in a lesson objective within the capacity limits of students, and they are likely to remember more of what they learned. Less is more!***

Optional

Time Limits of Working Memory. Working memory is temporary and can deal with items for only a limited time. How long is that time? This intriguing question has been clinically investigated for over a century, starting with the work of Hermann Ebbinghaus (1850–1909) during the 1880s. He concluded that we can process items intently in working memory (he called it short-term memory) for up to 45 minutes before becoming fatigued. Because Ebbinghaus mainly used himself as the subject to measure retention in laboratory conditions, the results are not readily transferable to the average high school classroom.

Any discussion of time limits for processing new information has to include motivation. People who are intensely motivated about a subject can spend hours reading and processing it. They are not likely to quit until they are physically tired. That is because motivation is essentially an emotional response, and we already know that emotions play an important part in attention and learning. Students are not equally motivated in all subjects. Therefore, these time limits are more likely to apply to students who are in learning episodes that they do not find motivating.

Peter Russell (1979) shows this time span to be much shorter and age dependent. More recent studies of the novelty-seeking brain of today are very similar (Medina, 2008; Portrat, Barrouillet, & Camos, 2008). The time span is, for preadolescents, about five to 10 minutes, and for adolescents and adults, about 10 to 20 minutes. These are average times, and it is important to understand what the numbers mean. An adolescent (or adult) normally can process an item in working memory *intently* for 10 to 20 minutes before mental fatigue (as opposed to physical fatigue) or boredom with that item occurs and the individual's focus drifts. For focus to continue, there must be some change in the way the individual is dealing with the item. For example, the person may switch from thinking about it to physically using it or to making different connections to other learnings. If something else is not done with the item, it is likely to fade from working memory.

This is not to say that some items cannot remain in working memory for hours, or perhaps days. Sometimes, we have an item that remains unresolved—a question whose answer we seek or a troublesome family or work decision that must be made. These items can remain in working memory, continually commanding some attention, and, if of sufficient importance, interfere with our accurate processing of other information.

Implications for Teaching. These time limits suggest that packaging lessons into 15- to 20-minute components is likely to result in maintaining greater student interest than one 40-minute lesson. It seems that, with many lessons, shorter is better! We'll talk more about lesson length and memory in Chapter 3.

Criteria for Long-Term Storage

Now comes the most important decision of all: Should the items in working memory be encoded to long-term storage for future recall, or should they drop out of the system? This is an important decision because we cannot recall what we have not stored. Yet teachers teach with the hope that students will retain the learning objective for future use. So, if the learner is ever to recall this information in the future, it has to be stored.

What criteria does the working memory use to make that decision? Figure 2.2 can help us here. Information that has survival value is quickly stored. You don't want to have to learn every day that walking in front of a moving bus or touching a hot stove can injure you. Strong emotional experiences also have a high likelihood of being permanently stored. We tend to remember the best and worst things that happened to us.

But in classrooms, where the survival and emotional elements are minimal or absent, other factors come into play. It seems that the working memory connects with the learner's past experiences and asks just two questions to determine whether an item is saved or rejected: "Does this make *sense*?" and "Does this have *meaning*?" Imagine the many hours that go into planning and teaching lessons, and it all comes down to these two questions! Let's review them.

- **"Does this make sense?"** This question refers to whether the learner can understand the item on the basis of past experiences. Does it "fit" into what the learner knows about how the world works? When a student says, "I don't understand," it means the student is having a problem making sense of the learning.
- **"Does this have meaning?"** This question refers to whether the item is *relevant* to the learner. For what purpose should the learner remember it? Meaning, of course, is a very personal thing and is greatly influenced by that person's experiences. The same item can have great meaning for one student and none for another. Questions like "Why do I have to know this?" or "When will I ever use this?" indicate that the student has not, for whatever reason, perceived this learning as relevant.

Here are two examples to explain the difference between sense and meaning. Suppose I tell a 15-year-old student that the minimum age for getting a driver's license in his state is age 16, but it is 17 in a neighboring state. He can understand this information, so it satisfies the sense criterion. But the age in his own state is much more relevant to him, because this is where he will apply for his license. Chances are high that he will remember his own state's minimum age (it has both sense *and* meaning) but will forget that of the neighboring state (it has sense but lacks meaning).

Information is most likely to get stored if it makes sense and has meaning.

Suppose you are a teacher and you read in the newspaper that the average salary for accountants last year was $60,000, whereas the average for teachers was $42,000. Both numbers make sense to you, but the average teacher's salary has more meaning because you are in that profession.

Whenever the learner's working memory perceives that an item does not make sense or have meaning, the probability of it being stored is extremely low (see Figure 2.4). If either sense or meaning is present, the probability of storage increases significantly (assuming, of course, no survival or emotional component). If both sense *and* meaning are present, the likelihood of long-term storage is very high.

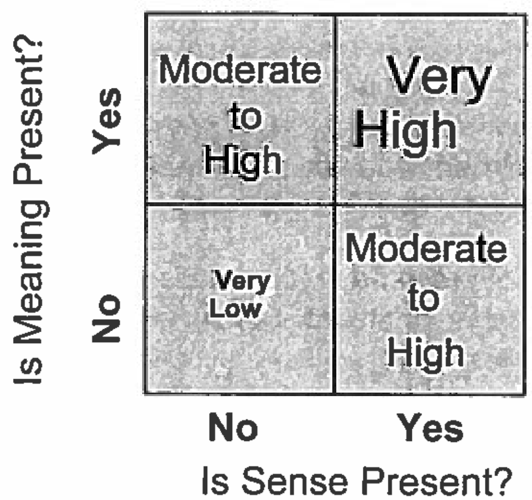

Figure 2.4 The probability of storing information varies with the degree of sense and meaning that are present.

Relationship of Sense to Meaning

Sense and meaning are independent of each other. Thus, it is possible to remember an item because it makes sense but has no meaning. If you have ever played *Trivial Pursuit* or similar games, you may have been surprised at some of the answers you knew. If another player asked how you knew that answer, you may have replied, "I don't know. It was just there!" This happens to all of us. During our lifetime, we pick up bits of information that make sense at the time and, although they are trivial and have no meaning, make their way into our long-term memory.

It is also possible to remember an item that makes no sense but has meaning. My sixth-grade teacher once asked the class to memorize Lewis Carroll's nonsense poem "Jabberwocky." It begins, *'Twas brillig, and the slithy toves did gyre and gimble in the wabe.* The poem made no sense to us sixth graders, but when the teacher said that she would call on each of us the next day to recite it before the class, it suddenly had great meaning. Because I didn't want to make a fool of myself in front of my peers, I memorized it and recited it correctly the next day, even though I had no idea what the sense of it was.

Brain scans and other studies have shown that when new learning is readily comprehensible (sense) and can be connected to past experiences (meaning), there is substantially more cerebral activity followed by dramatically improved retention (Maquire, Frith, & Morris, 1999; Poppenk, Köhler, & Moscovitch, 2010; Rittle-Johnson & Kmicikewycz, 2008).

Meaning Is More Significant. Of the two criteria, meaning has the greater impact on the probability that information will be stored. Think of all the television programs you have watched that are *not* stored, even though you spent one or two hours with the program. The show's content or story line made sense to you, but if meaning was absent, you just did not save it. It was *entertainment*, and no learning resulted from it. You might have remembered a summary of the show, or whether it was enjoyable or boring, but not the details. On the other hand, if the story reminded you of a personal experience, then meaning was present, and you were more likely to remember more details of the program.

Test Question No. 2: Learners who can perform a new learning task well are likely to retain it.

Answer: False. We cannot presume that because a learner performs a new learning task well, it will be permanently stored. Sense and/or meaning must be present in some degree for storage to occur.

Implications for Teaching. Now think of this process in the classroom. Every day, students listen to things that make sense but lack meaning. They may diligently follow the teacher's instructions to perform a task repeatedly, and may even get the correct answers, but if they have not found meaning after the learning episode, there is little likelihood of long-term storage. Mathematics teachers are often frustrated by this. They see students using a certain formula to solve problems correctly one day, but they cannot remember how to do it the next day. If the process was not stored, the information is treated as brand new again!

Sometimes, when students ask why they need to know something, the teacher's response is "Because it's going to be on the test." This response adds little meaning to a learning. Students resort to writing the learning in a notebook so that it is preserved in writing, but not in memory. We wonder the next day why they forgot the lesson.

Teachers spend about 90 percent of their planning time devising lessons so that students will *understand* the learning objective (i.e., make sense of it). But to convince a learner's brain to persist with that objective, teachers need to be more mindful of helping students establish *meaning*. We should remember that what was meaningful for us when we were children may not be necessarily meaningful for children today.

Past experiences always influence new learning. What we already know acts as a filter, helping us attend to those things that have meaning (i.e., relevancy) and discard those that don't. If we expect students to find meaning, we need to be certain that today's curriculum contains connections to *their* past experiences, not just ours. Further, the enormous size and the strict separation of secondary curriculum areas do little to help students find the time to make relevant connections between and among subjects. Helping students

Past experiences always influence new learning.

to make connections between subject areas by integrating the curriculum increases meaning and retention, especially when students recognize a future use for the new learning. Meaning is so powerful that most states prohibit trial lawyers from using what is dubbed the "golden rule" argument. It asks the jury, "If you were in this person's situation, what would you have done?"

Long-Term Storage

Storing occurs when the hippocampus encodes information and sends it to one or more long-term storage areas. The encoding process takes time and usually occurs during deep sleep. While learners may *seem* to have acquired the new information or skill in a lesson, there is no guarantee that storage will be permanent after the lesson. How do we know if retention has occurred? If the student can accurately recall the learning after a specific period of time has passed, we say that the learning has been retained. Because research on retention shows that the greatest loss of newly acquired information or a skill occurs within the first 18 to 24 hours, the 24-hour period is a reasonable guideline for determining if information was transferred into long-term storage. If a learner cannot recall new learning after 24 hours, there is a high probability that it was not permanently stored and, thus, can never be recalled. This point has implications for how we test students for retention of previously learned material. See the Practitioner's Corner at the end of this chapter on page 76 on how to test whether information is in long-term storage. Sometimes, we store only the gist of an experience, not the specifics. This may occur after watching a movie or television program. We store a generalization about the plot but few, if any, details.

Test Question No. 3: Reviewing material just before a test is a good practice to determine how much has been retained in long-term storage.

Answer: False. Reviewing material just before a test allows students to enter the material into working memory for immediate use. Thus, the test cannot verify that what the learner recalls actually came from long-term storage.

The long-term storage areas are represented in the model (Figure 2.1) as file cabinets—places where information is kept in some type of order. I have resisted the temptation to replace the file cabinets in the model with a more technologically current storage device—such as a computer hard drive or flash drive. As you may recall, I mentioned earlier the inadequacy of comparing brain functions to computer operations, and introducing such a storage device into the model would contradict that comparison.

Although there are three file cabinets in the diagram for simplicity, we do not know how many long-term storage sites actually are in the brain. Memories are not stored as a whole in one place. Different parts of a memory are stored in various sites that reassemble when the memory is recalled. Long-term memory is a dynamic, interactive system that activates storage areas distributed across the brain to retrieve and reconstruct memories.

Long-Term Memory and Long-Term Storage

This is a good place to explain the difference between the terms *long-term memory* and *long-term storage,* as I use them in the model. Long-term memory refers to the process of storing and retrieving information, while long-term storage refers to the areas in the brain where the memories are kept.

Optional

The Cognitive Belief System

The total of all that is in our long-term storage areas forms the basis for our view of the world around us. This information helps us to make sense out of events, to understand the laws of nature, to recognize cause and effect, and to form decisions about goodness, truth, and beauty. This total construct of how we see the world is called the *cognitive belief system.* It is shown in the information processing model as a large triangle extending beyond the long-term storage areas (file cabinets). It is drawn this way to remind us that the thoughts and understandings that arise from the long-term storage data are greater than the sum of the individual items. In other words, one marvelous quality of the human brain is its ability to combine individual items in many different ways. As we accumulate more items, the number of possible combinations grows exponentially.

Because no two of us have the same data in our long-term storage (not even identical twins raised in the same environment have identical data sets), no two of us perceive the world in exactly the same way. People can put the same experiences together in many different ways. To be sure, there are areas of agreement: gravity, for example (few rational people would dispute its effects), or inertia, as most people have experienced the lurch forward or backward when a moving vehicle rapidly changes speed. There can be strong disagreement, however, about what makes an object or person beautiful, or an act justified. The persistent debates over abortion and capital punishment are testimony to the wide range of perspectives that people have over any issue. These differences reflect the ways individuals use the experiences in their long-term storage areas to interpret the world around them.

Here is a simple example of how people's experiences can cause them to interpret the same information differently. Close your eyes and form the mental image of an "old bat." Go ahead, try it! What picture comes to mind? For some baseball fans, it might be a marred wooden club that has been in too many games. A zoologist, however, might picture an aging fruit bat as it flies haltingly among the trees in search of food. Still others might recall an old hag whose complaining made their lives unpleasant. Here are at least three very different images generated by the same two words, each one formed by individuals whose experiences are different from the others.

> ***The cognitive belief system is our view of the world around us and how it works.***

Self-Concept

Deep within the cognitive belief system lies the *self-concept.* While the cognitive belief system portrays the way we see the world, the self-concept describes the way we view ourselves in that world. I might conceptualize myself as a good softball player, an above-average student, or a poor mathematician. These and a long list of other descriptions form part of a person's self-concept.

The self-concept is represented in the information processing model (Figure 2.1) as a face and is placed at the apex of the triangle to emphasize its importance. *Self-concept* is used here as a neutral term that can run the gamut from very positive to very negative (Figure 2.5). The face on the diagram of the model has a smile, indicating a positive self-concept. But for some people, the face might have a frown because they may not see themselves as positive beings in their world. Emotions play an important role in forming a person's self-concept.

Self-Concept and Past Experiences

optional

Our self-concept is shaped by our past experiences. Some of our experiences, such as passing a difficult test or getting recognition for a job well done, raised our self-concept. Other experiences, such as receiving a reprimand or failing to accomplish a task, lowered our self-concept. These experiences produced strong emotional reactions that the brain's amygdala encoded and stored with the cognitive event. These emotional cues are so strong that we often reexperience the original emotion each time we recall the event. Over time, new positive and negative experiences moderate the self-concept and alter how we see ourselves in our world.

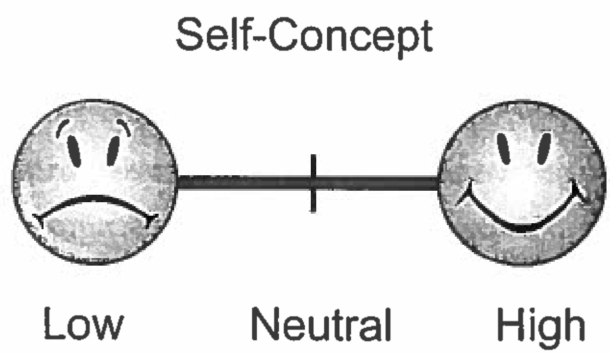

Figure 2.5 Self-concept describes how we see ourselves in the world. It can range from very low to very high and can vary with different learning situations.

Accepting or Rejecting New Learning

Remember that the sensory register and temporary memory systems use past experiences as the guide for determining the importance of incoming stimuli to the individual. Thus, if an individual is in a new learning situation and past experience signals the sensory register that prior encounters with this information were successful, then the information is very likely to pass along to working memory. The learner now consciously recognizes that there were successes with this information and focuses on it for further processing. But if past experiences produced failure, then the sensory register is likely to block the incoming data, just as venetian blinds are closed to block light. The learner resists being part of the unwanted learning experience and resorts to some other cerebral activity, internal or external, to avoid the situation. In effect, the learner's self-concept has closed off the receptivity to the new information. As mentioned earlier in the discussion of the hierarchy of data processing, when a curriculum concept struggles with an emotion, the emotion almost always wins. Of course, it is possible for the rational system (frontal lobe) to override the emotions, but that usually takes time and conscious effort.

Let us use an example to explain this important phenomenon. Someone who was a very successful student in mathematics remembers how that success boosted self-concept. As a result, the individual now feels confident when faced with basic mathematical problems. On the other hand, for someone who was a poor mathematics student, lack of success would lower his or her self-concept. Consequently, such an individual will avoid dealing with mathematical problems whenever possible—a condition known as *math anxiety*. People will participate in learning activities that have yielded success for them and avoid those that have produced failure.

Implications for Teaching. Students who experience self-concept shutdown in the classroom often give signs of their withdrawal—folding their arms, losing themselves in other work, or causing distraction. Too often, teachers deal with this withdrawal by reteaching the material, usually slower and louder. But they are attacking the problem from the front end of the information processing system, and this is rarely successful. It is the equivalent of putting a brighter light outside the closed venetian blinds, hoping the light will penetrate. If the blinds are fully closed and effective, no light will get through, regardless of how bright it may be. In other words, the learner's decision to ignore the material is successful.

The better intervention is to deal with the learner's emotions and convince the learner to allow the perceptual register to open the blinds and pass the information along. But because the self-concept controls the blinds, the learner must believe that participating in the learning situation will produce new successes rather than repeat past failures. When teachers provide these successes, they encourage students to open the sensory register and, ultimately, to participate and achieve in the once-avoided learning process. In short, the self-concept controls the feedback loop and determines how the individual will respond to almost any new learning situation. Recognizing this connection gives teachers new insight on how to deal with reluctant learners.

> ***People will participate in learning activities that have yielded success for them and avoid those that have produced failure.***

optional

Learning Profiles (Styles)

Experienced teachers have recognized for years that students learn in different ways. Several decades ago, psychologists and educators began to talk about "learning style" models that could describe the preferences that students had while learning. Rita and Kenneth Dunn (1993) developed one popular model in the 1970s that was organized around five categories: environmental, emotional, sociological, physiological, and psychological preferences. The Dunns suggested that students could achieve more if teachers tailored their instructional strategies to a student's individual learning style. Over the years, several more models emerged, and the learning style was also used to describe other variables involved in learning, such as intelligence preferences and cultural influences. Because of the proliferation of these models and the inclusion of other factors, the term *learning style* itself suffered from a vagueness that challenged researchers who wanted to determine whether its components really had an impact on student achievement.

In the late 1990s, Carol Ann Tomlinson (1999) proposed the broader term, *learning profile,* that included four elements of how individuals process, remember, and use what they learn: learning styles, intelligence preferences, culture, and gender. Despite this broader definition, the whole area

> ***Teachers tend to teach the way they learn.***

of learning preferences remains the subject of considerable debate among researchers and educators. There is little argument that people have various internal and environmental preferences when they are learning. Hundreds of books and articles have been written, both supporting and questioning the notion of learning styles. What is not yet resolved is whether these preferences really matter and whether teachers need to consider them when selecting classroom instructional strategies or when working with individual students. Some researchers argue that teachers should not be using up valuable time assessing students' learning style, but should be using that time to design instruction so that it addresses all styles (Pashler, McDaniel, Rohrer, & Bjork, 2008).

One component of learning styles that educators have discussed for years is sensory (or modality) preferences. You hear comments such as "I learn best when I can see it" or "I need to get involved in my learning through hands-on activities." These are expressions of sensory preferences. Because teachers tend to teach the way they learn, it might be useful for teachers to know their own sensory preferences.

Sensory Preferences

optional

Although we use all five senses to collect information from our environment, they may not contribute equally to our knowledge base. Most people do not use sight, hearing, and touch equally during learning. Just as most people develop a left- or right-handed preference, they also develop preferences for certain senses as they gather information from their environment. Some people have a preference for learning by seeing, for example. They are called visual learners. Others who use hearing as the preferred sense are known as auditory learners. Still others who prefer touch or whole-body involvement in their learning are called kinesthetic/tactile learners. These sensory preferences are an important component of an individual's learning profile.

No one knows exactly why we have these sensory preferences, but most people acknowledge them on a self-assessment instrument. One possibility is that certain genetic factors combine to enhance the neural networks that process one sense's information better or faster than another's. There could also be an organic reason. For example, recent studies have revealed an astonishing 77 percent jump in hearing loss among 12- to 19-year-olds in 2006 compared to the same age group in the mid-1990s (Shargorodsky, Curhan, Curhan, & Eavey, 2010). Researchers attribute this loss—at least in part—to the loud music that adolescents listen to for long periods through their earphones, in their cars, and at discotheques. Given its plasticity and recuperative powers, it is possible that the brain strengthens other sensory networks—visual processing, for example—to compensate for the reduction in auditory capabilities.

Here, too, cognitive neuroscientists caution that teachers should not interpret the notion of sensory preferences to imply that teaching a student predominantly in that student's preferred sense will improve learning or retention. In fact, the little research evidence in this area suggests that it will not (Krätzig & Arbuthnott, 2006). Rather, the evidence suggests that using *multisensory* activities during a learning episode improves student learning and retention (Ginns, 2005). Nonetheless, the existence of sensory preferences means that teachers need to do the following:

Optional

- Realize that these sensory preferences are just that—preferences, *not* exclusivities. It is nonsensical to say that a typical student is "just a visual learner." We learn best when many senses are involved.
- Understand that students with different sensory preferences will behave differently during learning.
- Recognize that they tend to teach the way they learn. A teacher who is a strong auditory learner will most likely use a lot of lecture when teaching. Students who also are strong auditory learners will feel comfortable with this teacher's methods, but visual learners may have difficulty maintaining focus. They will doodle or look at other materials to satisfy their visual craving. Note, similarly, that students with auditory preferences want to talk about their learning and can become frustrated with teachers who use *primarily* visual strategies. Strong kinesthetic learners require movement while learning, or they become restless—tapping their pencils, squirming in their seats, or walking around the room.
- Avoid misinterpreting these variations in learning profile behavior as inattention or as intentional misbehavior. The variations may, in fact, represent the natural responses of learners with different and strong preferences.
- Understand that a teacher's own learning profile and sensory preferences can affect learning and teaching. Teachers should design lessons that include activities to address all sensory preferences and learning profiles.

WHAT'S COMING UP?

This completes our trip through the information processing model. Remember that the brain is a parallel processor and deals with many items simultaneously. Even though it rejects much data, it always stores some. The next chapter will examine the nature of memory and the factors that determine and help in the retention of learning.