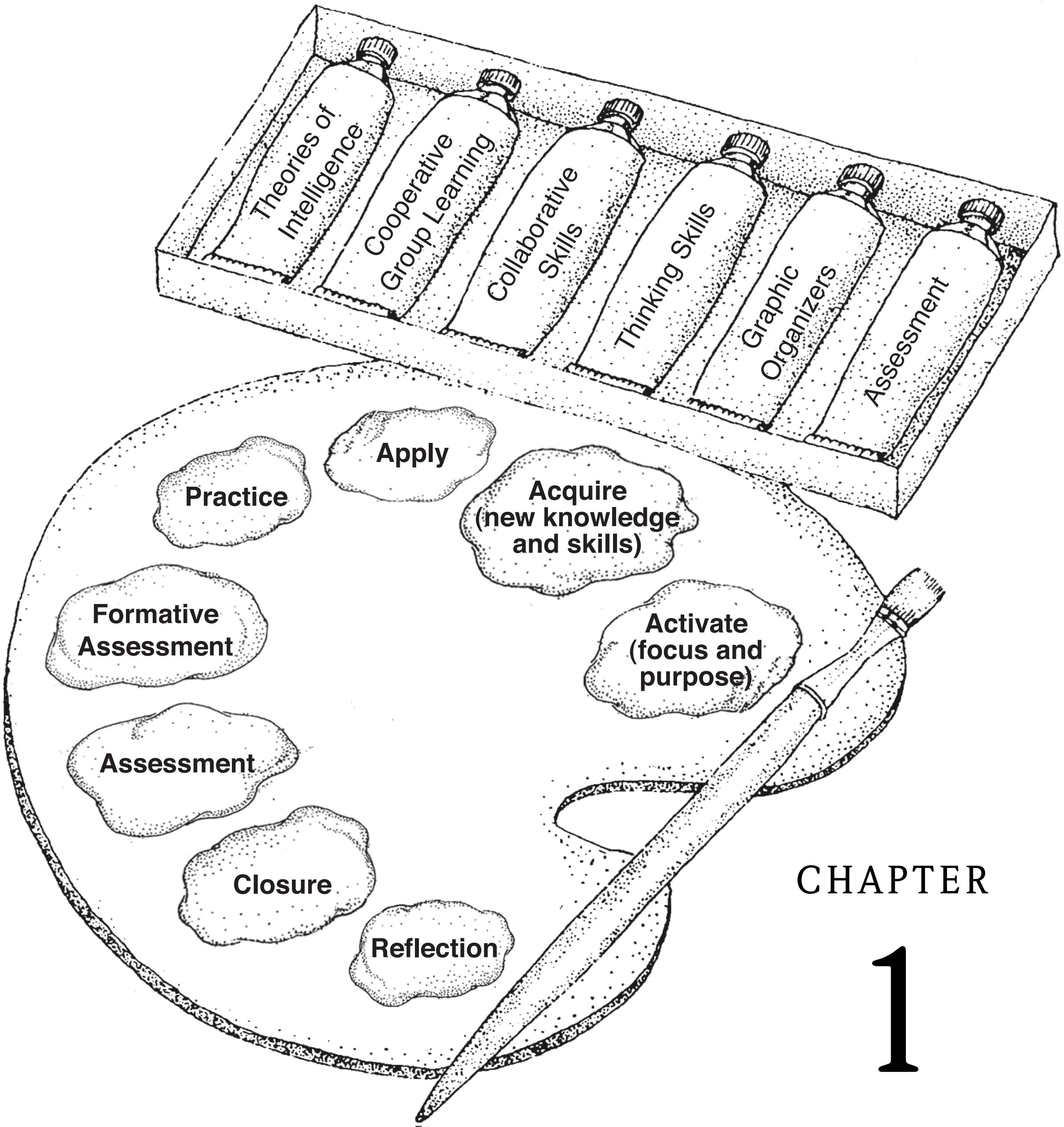


CHAPTER

1

Cognitive Research

CHAPTER 1

COGNITIVE RESEARCH

WHAT IS IT?

Much of what is known about how the brain learns has been discovered in the past twenty-five years. For the first time, scientists are able to examine the internal organization and working of the brain as opposed to merely observing the external behavior that results from brain activity. The advent of brain-imaging technology has provided a window into the skull that allows scientists and researchers to observe how and where information is manipulated in the process we call learning. The CAT (computerized axial tomography) scan can create a graphical three-dimensional image of the brain. The PET (positron-emission tomography) scan can monitor the pattern of blood flow to various parts of the brain and allows observers to see which parts "light up" as the brain processes information.

Cognitive researchers are just beginning to understand how the brain interacts with the external environment to acquire information, to manipulate and process it, to store it as memory, and to retrieve it on demand. Educators, neuroscientists, cognitive psychologists, and researchers such as Renate Nummela Caine, Geoffrey Caine, Marian Diamond, Gerald Edelman, Howard Gardner, Jane Healy, Eric Jensen, Robert Sylwester, and Pat Wolfe have provided a variety of theories of how the brain learns.

The Brain Is Like . . .

The organization and functions of the brain are predicated on a number of very complex ideas. One way to understand these complex ideas is through the use of metaphors and analogies. These comparisons afford us a place to begin our understanding of the brain, and although they provide somewhat distorted representations, they give us approximations that simplify complex ideas.

One discovery from research is that the brain makes sense of the world by constructing meaning from the information around it (Caine and Caine 1994). One way it does this is by connecting information about something it already knows to the new concept that it is trying to understand. For example, we can use the computer (something we know about) as an analogue for the brain (something we are trying to learn about). We then can take our knowledge about computers and apply it to the brain in an attempt to understand it.

The computer analogy works well for most people when trying to learn about the networks of brain cells and the ways in which they are connected, especially if they already understand networks, connections, and wires. However, the analogy breaks down when we use it to explain how the brain is organized or how it transmits information.

To explain these concepts we need another analogy—the jungle. Neurobiologist Gerald Edelman (1992) proposed that the organization and functions of the brain are more analogous to a jungle or a rain forest than they are to a computer. According to his theory, the brain is a rather messy and disorganized place. Like a jungle, it has no external controller and few predetermined goals other than to survive. In fact, survival is its primary function. Survival also is the main reason that the brain engages in learning. In a jungle, no outside agency or group is in control; each species of plant and animal goes about its own business, never thinking that it is part of a master plan. However, each organism is, in fact, part of a system within other interdependent systems, which together form one giant ecosystem. All the animals and plants have the capacity to thrive and reproduce, but some do and some don't; this is natural selection at work. The jungle does not tell the individual species *how* to survive; it merely supports the survivors.

The brain is organized in a similar fashion. No one part of the brain is in charge, and the brain is made up of myriad interconnecting systems. Each system goes about its own business but also contributes information that allows the brain to survive.

All systems in the brain have the capacity to survive. As in the jungle, some systems thrive, some don't. The brain supports the winners, which are the neural systems that are stimulated by their environments and frequently used. This process operates similarly to the way in which we retain many of our physical capabilities—we either use them or lose them. Just as muscles become stronger through use and weaker through disuse, neural networks that are used strengthen and those that are not used weaken. When a neural network weakens, the cells within it may become rededicated to other uses. This is called neural pruning.

An example of neural pruning is evident in the process of language acquisition. We are born with the capability to make all the sounds and learn the vocabularies and grammatical structures of every language spoken by humans. In many cases, however, we learn only one. The networks not found in one's native tongue eventually weaken through a lack of use and, in some cases, are lost forever.

The "double 1" sound in the Welsh language, found in words such as Llangollen and Llewelyn, is a case in point. If one does not learn the sound early, the chance of being able to acquire it later is not very promising. Similarly, native speakers of Cantonese who learn English as adults often have difficulty with the "th" sound in English words, whereas Chinese children raised in English-speaking environments have no such difficulty.

The brain has two primary kinds of cells: nerve cells and glial cells. The nerve cells, called neurons, form a complex network that transmits information to all parts of the brain/body system. To visualize a neuron, imagine an old-fashioned floor mop with a wooden handle and a head made from twisted cotton fibers. Now imagine that the handle has begun to split apart. The dense part of the mop represents the cell body, and the individual strands of the mop are the dendrites. The stick is the axon, which is an extension of the cell body, and the split ends of the stick represent the axon terminals (see Fig. 1.1).

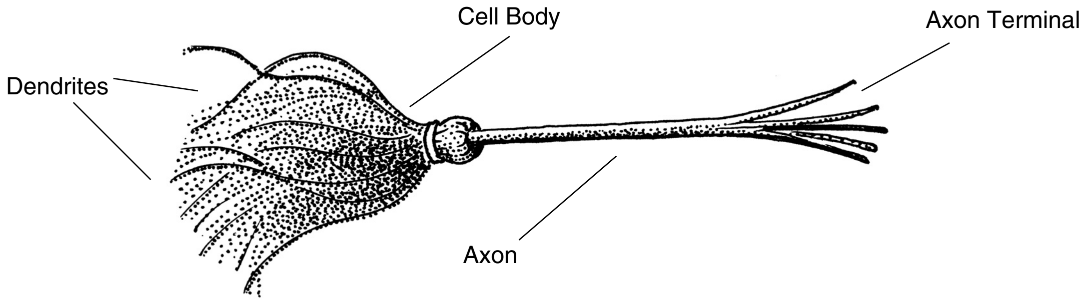


Figure 1.1

In reality the dendrites are a complex array of filaments like hairs that grow out of the cell body. The axon is a snake-like projection that can vary in length from a few millimeters in the brain to several feet in the spinal cord, and the axon terminals are the staging area for the chemical messengers called neurotransmitters. An actual neuron would look more like Figure 1.2.

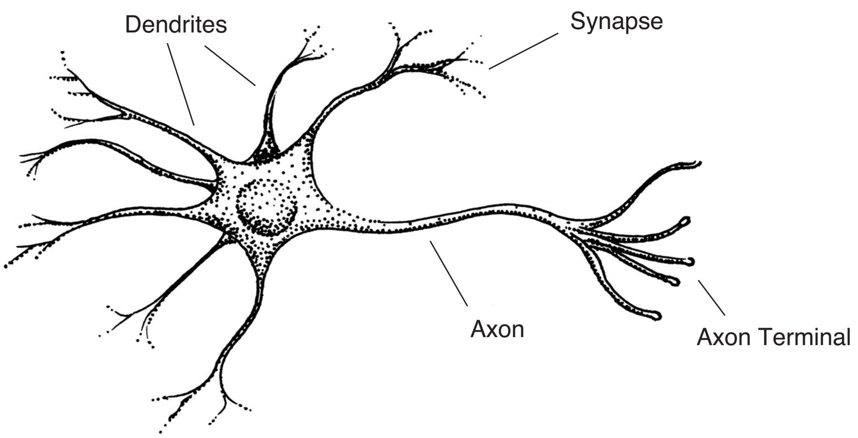


Figure 1.2

Now imagine that our floor mop representation is matched up with a series of other floor mops arranged head to tail. When neurons connect like this, they begin to form a neural network. The axon terminals of the first neuron send a message, which is passed on to the dendrites of the second neuron. The second neuron passes the message on to the next cell in line until the message gets to its final destination. The message is carried by molecules called neurotransmitters, which are, in fact, chemical messengers. Neurotransmitters cross the space between one neuron and the next. This space, or gap, is called a synapse (see Fig. 1.3).

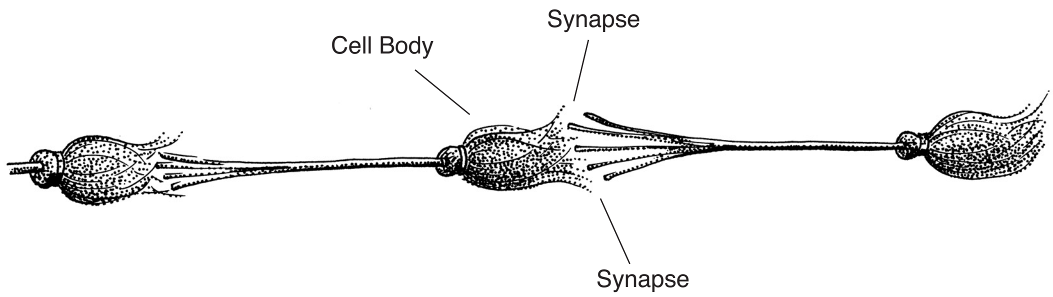


Figure 1.3

More than fifty different kinds of neurotransmitters have been identified (Sylwester 1995), but they all have one of two basic functions—they either excite the system or calm it. For example, glutamate, an amino acid compound, stimulates the system, whereas gamma-aminobutyric acid (GABA), also an amino acid compound, inhibits it.

One large group of neurotransmitters is made up of peptides. Peptides travel along a chain of neurons to all parts of the brain and the body. They elicit a wide range of responses from pleasure to pain. Peptides have a powerful effect on our emotional lives because they control our feelings and, hence, our responses to the outside world. They also control the internal regulating mechanisms of the body by telling them things such as when to shed excess heat, when to conserve it, when to eliminate fluids, when to store them, and so on. In general terms, the peptides tell all bodily systems and functions what to do, when to do it, and how to do it (see Fig. 1.4, page 6).

Cortisol and endorphins are two neurotransmitters that are peptides. Cortisol activates the body's defense systems as a reaction to the stress caused by a perceived threat. For example, when the body perceives a threat, the adrenal glands distribute cortisol, which elevates the cholesterol level and releases clotting agents into the blood. This was useful for our ancestors, who often faced physical dangers such as broken bones and flesh wounds. In modern times, however, stress more often is a result of emotional causes than physical ones. Because the body responds to both emotional and physical threats in the same manner, this can result in inappropriate responses to stress. In situations of chronic stress, high levels of cortisol can cause feelings of extreme despair and, in some cases, can cause the destruction of neurons related to both learning and memory (Vincent 1990).

Endorphins are a class of peptides that can decrease pain and increase pleasure. They are released both when a person is in pain and when a person is engaged in pleasurable activities such as games, dancing, and other social interactions.

Close-Up of a Synapse

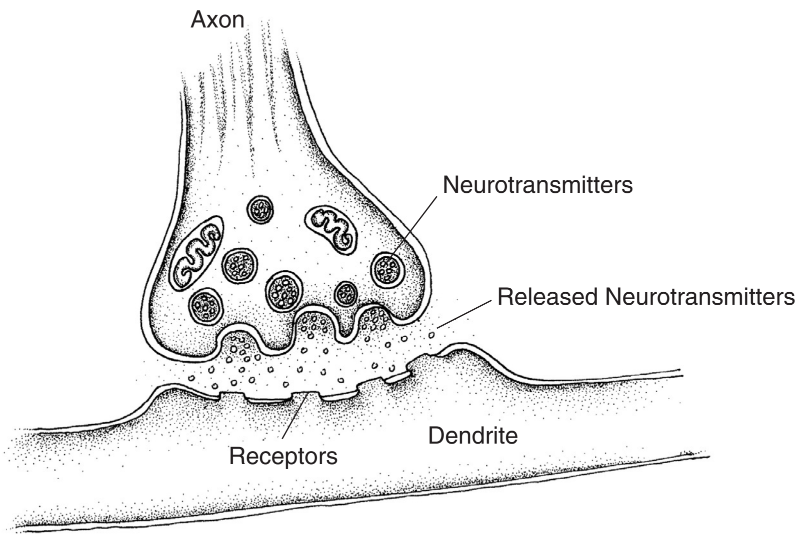


Figure 1.4

Endorphins are often released when a person receives overt signs of support, affection, and positive regard. Classrooms that encourage a relaxed, enthusiastic, and cooperative approach to learning are usually perceived as enjoyable because they stimulate the release of endorphins (Sylwester 1995).

Glial cells, the other primary type of brain cells, perform a number of support functions for the nerve cells. One of these is to provide insulation in the form of a myelin sheath that prevents a short circuit of information between one nerve cell and the next.

Although the brain weighs only about three pounds, it is responsible for the cathedrals of Europe, the mobile home, the works of Shakespeare, *Sesame Street,* Beethoven's sonatas, and punk rock. In fact, everything that defines human culture is a product of the brain.

Brain Organization and Architecture

The brain is enormously complex. Some scientists speculate that there are more possible connections in the brain than there are pieces of matter in the universe. The brain has about 100 billion neurons, each of which can produce up to 20,000 connections in the form of dendrites. Each neuron, therefore, is capable of connecting with other cells in an almost infinite variety of ways. This profusion of connections gives the brain its amazing powers to think, learn, and create.

The brain can be divided into three parts, lower, middle, and upper, but in effect, it functions as a highly interactive and profusely connected whole. Because the functions of the lower and middle brain are so elaborately connected, they are often described as one unit called the emotional brain. This unit is responsible for monitoring many of the physical processes of the body, including heartbeat, respiration, digestion, sexual activity, and body temperature. It also controls many of the functions associated with the emotions and the formation of memories. The emotional brain has many other functions critical to our survival. Apart from its ability to recognize and react to sudden changes that signal danger, it also monitors all the other more gradual or subtle changes going on around us, such as room temperature, hunger, hormone cycles, and the waking and sleeping cycles. It also evaluates all the incoming information provided by the senses—sight, hearing, touch, taste, and smell. It then decides which information is important enough to be singled out for attention by the rest of the brain. The third and most complex part of the brain is the cerebral cortex, which handles language, perceives patterns, decodes symbols, and performs all the functions associated with higher-order thinking and reasoning. The cells of the cortex are organized into several million interconnecting and overlapping systems, or networks, each of which processes a small piece of information. Each piece of information is then connected to other pieces in a system that allows us to think, solve problems, remember past experiences, and plan for the future. The cortex is the most complex part of the brain and the least understood. The individual systems of the cortex interact not only with each other but also with the systems of the emotional brain. They work together to form a comprehensive alerting or arousal system that establishes the degree of emotion and/or attention. That sets the stage for the ways in which we respond to both danger and opportunity. Sometimes the response may be a slow and well-considered action that results from thinking through a problem. At other times, it may be a hasty and seemingly ill-considered reaction to a highly charged emotional stimulus. Sometimes the response is a life-or-death decision to jump out of the way of a speeding truck before the thinking parts of the brain have even registered the problem.

Left and Right Hemispheres

The right and left hemispheres of the brain perform different but totally interdependent functions. In simple terms, the right hemisphere takes in great gulps of information, and the left hemisphere analyzes and sorts that information. Working together, the right and left sides of the brain deal with information as both wholes and parts. The right brain is global or panoramic in its approach to information. The left brain is more logical and linear; it controls activities such as speech, logical thinking, and the manipulation of symbols and numbers. The section on Creative and Critical Thinking in chapter 7 shows how both sides work together in decision making and problem solving. Two strategies called *concept formation* and *concept attainment,* also discussed in chapter 7, illustrate how the brain seeks patterns and makes wholes from parts. Elkhonon Goldberg (2001) provides us with an alternate theory of right brain/left brain organization. He suggests that the right hemisphere is organized to confront new challenges and deal quickly with situations that the brain has not previously encountered. He postulates that this is all part of the brain's primary mandate, which is survival. For example, the face of a stranger represents a novel situation that may pose a threat. The right side of the brain therefore quickly processes this information. Familiar faces, which presumably pose no threat, are processed on the left.

Both hemispheres are active in learning situations. When we are learning new skills, information processing is principally a right-hemisphere operation. As we come closer to mastery of the skill, more of the processing is transferred to the left side. The right hemisphere responds to new situations with a solution, which is typically rapid but not necessarily appropriate. The left hemisphere selects the most promising responses and devises strategies and systems to deal with similar situations in the future.

Whole Brain Theory

Because the right and left sides of the brain continually interact in much more complex and interactive ways than previously thought, many scientists now believe in what is called a whole-brain approach to learning; this theory says, in effect, that nearly every part of the brain is involved in nearly every activity of the brain (Goldberg 2001). This modifies many of the earlier notions of brain organization, such as Sperry's (1968) right brain/left brain theory and MacLean's (1978) theory of the triune brain.

WHY DO WE NEED IT?

In the past, schools have often been accused of teaching "the facts, the whole facts, and nothing but the facts." The "facts" then were memorized, trotted out for the test, and promptly forgotten. Even when they were not forgotten, the facts were rarely connected and often were misunderstood. Nevertheless, some people still define education as the ability to recall a vast number of facts.

A more rational definition of education maintains that what counts is not the sheer number of facts a person knows but what a person does with those facts. Facts become useful when they are used to solve problems or extend knowledge. This does not mean that schools should give up teaching facts. Nor does it mean that students should not train their memories to recall important information. It does suggest, however, that we need to spend more time in teaching students to sort and classify discrete facts into categories and to deal with information at a conceptual level. Both the process of memorizing facts and the process of forming concepts are necessary elements of learning.

Learning is a search for meaning, yet most of us have only a rudimentary notion of how meaning is created. According to Eric Jensen (1996), meaning is created when new information is connected at the neural level to information that already has meaning or relevance for the learner. The more closely the new information conforms to what the learner perceives as interesting, useful, and emotionally stimulating, the more likely it is to be integrated and learned.

Nearly everything we learn has an emotional element. Whenever the emotions are engaged, the brain releases a battery of chemical messengers (neurotransmitters) that mark the event and signal its importance to the brain. This focuses the learner's attention and, in doing so, facilitates learning. The emotional context, thus, becomes part of the matrix or pattern to which the new learning is attached. What has in fact been created is a neural organizer, or a place where information sticks—a kind of Velcro for the mind.

By understanding how the brain, the body, the emotions, and learning are interdependently connected, we can get a sense of how these ideas relate to the concept called brain-compatible learning. If we consider the work of Daniel Goleman (1995) on emotions and learning, the work of Marian Diamond (1988) on the effects of experience and learning, and the work of Renate Nummela Caine and Geoffrey Caine (1994) on the connection of information and learning, we can see how these theories not only support each other but also support and extend the concept of brain compatible learning. By adding information from the work of Gerald Edelman (1987) about his notion of neural Darwinism, which describes the brain as a richly interconnected whole in which the parts that are successful are retained and nurtured while other parts die off, and backing this up with Robert Sylwester's (1995) lucid overview of current research in *A Celebration of Neurons,* the characteristics that define brain compatible learning become even clearer.

Understanding how the brain learns—by actually capturing, sorting, and holding on to information—enables teachers to implement the kinds of instruction and develop the kinds of classrooms that capitalize on the brain's natural abilities and thus promote student learning.

HOW DO WE DO IT?

The field of cognitive research is vast, complex, and continually expanding. New discoveries are being made and old theories are updated or discarded almost on a weekly basis. Although many prior assumptions have been reinterpreted, based on more current information, a central core of knowledge about how the brain learns remains unchallenged.

The following pages contain a digest of just some of the current theories in the fields of cognitive science, cognitive psychology, and educational research. The underlying premise of these theories is that if we understand how the brain learns, we can use that information to improve classroom practice.

Emotion and Learning

The connection between the thinking parts of the brain and the emotional or survival-oriented parts of the brain is of particular importance to teachers. When a human being experiences stress, the body reacts by producing a battery of hormonal and electrochemical changes.

If the level of stress is perceived as critical, the brain may go into a survival mode by transferring the locus of control to more survival-oriented part of the brain. In the past, this phenomenon was referred to as "downshifting"; psychologist Daniel Goleman (1995) referred to it as "emotional hijacking." In a recent article, Robert Sylwester (1998) made a proposal that rather than downshifting, the brain transfers control to part of the brain that is better equipped to deal with the situation at hand. In situations that pose a clear-and-present danger, the body reacts before the cerebral cortex (the thinking part of the brain) has had a chance to review what's happening and process all the information. This is why we are able to jump out of the path of a speeding truck before we have consciously registered its presence. Before incoming information is processed by the cerebral cortex, it is filtered through the reticular formation, the brain's gatekeeper. The reticular formation monitors incoming information and decides if it is life threatening or potentially dangerous. This information is transmitted to the amygdala, the brain's alarm system. The amygdala is connected to other parts of the brain in a way similar to how many home alarm systems are connected to the police and fire services (Sylwester 1995). In a threatening situation, these parts of the brain respond to the amygdala's message by causing a release of hormones. These, in turn, alert those parts of the body needed for survival, such as the cardiovascular system, the digestive system, and the muscles. This results in a heightened state of physical preparedness in which so much attention is focused on survival that the thinking parts of the brain may relinquish much of their control and allow the emotional brain to take over. There are educators who believe that stress is an effective motivator for learning. Psychiatrist Arnold Scheibel (1994) maintained that lessons learned under stress are remembered better than those learned in nonthreatening environments. He bases this on the fact that the neurotransmitters and hormones released under duress result in a heightened state of being. This allows the brain and body to function more effectively because they are now on alert status.

As teachers, we need to differentiate between eustress, the positive feelings of enjoyment or excitement that one experiences when engaging in something new and different, and distress, the negative feelings that may cause one to panic or revert to survival behaviors. Eustress comes from the same root word as euphoria it puts us into a state of heightened awareness in which our ability to learn is at its optimum level. Distress has the opposite effect and triggers the release of neurotransmitters, such as cortisol, that may cause the thinking parts of the brain to function below peak efficiency (Vincent 1990). It appears, then, that a certain amount of stress may be beneficial, whereas acute or prolonged stress may have negative effects on learning.

If students are to learn efficiently, stress needs to be kept within tolerable levels so that their self-esteem and personal efficacy remain intact. Strategies such as cooperative group learning and metacognitive reflection, which promote social interaction and allow students to discuss their emotions, are effective tools for creating a tolerable level of stress and, hence, a climate conducive to learning.

Assignments that create a challenge without imposing a threat are essential for learners to feel confident and committed to a task. This creates a sense of "relaxed alertness" (Kohn 1993). In classrooms where teachers differentiate the instructional process by using "adjustable assignments" (Gregory and Chapman 2002), students are challenged at their level of ability or abstraction.

If we reflect, most of us can recall situations that may have caused students to react with a visceral rather than a cognitive behavior. In extreme cases, this may lead to the fight-or-flight response in which a student may exhibit aggressive behavior or language (fight) or even run from the room (flight). As far as the brain is concerned, actions speak louder than words. Everything that happens in the classroom is monitored by three parts of the brain, two of which have no spoken language but are very adept at reading body language and tone of voice. Every gesture, every inflection, and every invasion of personal space is monitored by the emotional brain and evaluated in terms of its threat potential. These skills allowed our ancestors to survive, and they are still alive and well in all of us.

The implications of emotion in the teaching and learning process seem too important to be left to chance. It seems vital that teachers understand the physiological processes operating and are cognizant of how these forces act on the students. The classroom environment, the ways in which questions are asked of students, and the amount of wait time between question and response may all represent a perceived threat and thus cause the brain to react at an emotional level. Figure 1.5 lists some indicators that help create and support a positive learning environment.

Indicators for Classroom Climate

Positive	Negative
Provide attractive surroundings	Sterile surroundings
Include plants and decorative walls	Student work not displayed
Student work displayed	Poor, inappropriate lighting
Low-stress lighting	Negative attitude of teacher
Encouraging teacher	"One size fits all" mentality
Offer choice and variety	Unnecessary pressure
Provide wait time	Little or no feedback
Provide think time	Challenge inappropriate
Offer constructive feedback	Teaching to the "middle"
Offer appropriate challenge	Everyone does the same task regardless of style or multiple intelligence strengths
Ensure safety	
Ensure relaxed alertness	
Consideration of learning styles	

Figure 1.5

Everything else teachers do, in terms of curriculum or instruction, may be irrelevant if the students cannot remain in a state where the functions of the emotional brain are integrated and harmonized with the capabilities of the thinking, reasoning parts of the brain.

Emotion, Attention, and the Formation of Memories

The cortex is the seat of higher-order thinking, but it relies on its connections with the emotional brain for a number of vital functions in the learning process. These functions are concerned with the engagement of emotions, the focusing of attention, and the formation of memories. The human mind can consciously focus on only one thing at a time, and it is our emotions, mediated by the emotional brain, that dictate to what we pay attention. There is an emotional component to all learning and it seems to work like this:

Emotion focuses our attention,
and attention sets the stage for learning.
Even people who appear to be multitasking are,
in reality, switching their attention from one task to another.

Emotion also plays a role in the formation of memories. Events with a high degree of emotional impact seem to stay in most people's minds with no conscious effort. Most of us can recall with clarity and precision the pivotal events of our lives. Among the more famous examples of emotionally charged events are the assassination of President Kennedy, the *Challenger* disaster, the death of Diana, Princess of Wales, and the events of September 11, 2001. It seems that everyone alive at the time of these events can remember in some detail where they were and what they were doing when they first heard about them.

Information that has an emotional context seems to be more readily recalled, and by recalling the emotional context, we also can usually recall the details of the event. This is why strategies that engage the emotions are such powerful learning tools. Activities such as role plays, simulations, debates, and discussions all provide emotional hooks that facilitate the recall of information.

Memory Systems

Memory has been described as being both like a sponge that soaks up information and like a muscle that gets stronger with use. Neither of these metaphors is particularly accurate. A more apt description is that memory is a process, not a thing. Pat Wolfe, a noted educational consultant, described how the processes of memory and learning are inextricably linked in the following way: "We say we have learned something. We also could say we have gotten something into memory" (Wolfe 1998).

The way the brain processes memory can be compared to the memory processing model shown in Figure 1.6 (page 14), which shows how sensory memory, working (or short-term) memory, and long-term memory are processed. The strategies at the bottom can be used at different stages in the learning process to garner, rehearse, or access stored memory.

Sensory Memory

Sensory memory acts like a sieve, or filter, to screen out much of the input that comes from our senses and internal organs. Without this filter, we would drown in a sea of information. Sensory memory decides which information should be passed on to short-term memory and which information should be discarded. The decisions are influenced by three additional processes: perception, expectation, and attention.

Perception is the process whereby the brain attaches meaning to what the senses perceive. This is affected by the patterns of experience that the brain previously has acquired and therefore what it expects to see. For example, if you were told that the figure below was a number, you would perceive it as a thirteen.

13

However, if you were told to expect a letter you would see it as a **B**. Even though the figure remained the same, what you expected to see altered your perceptions. The way that the brain interprets information depends on neural networks that have been built up as a result of experience.

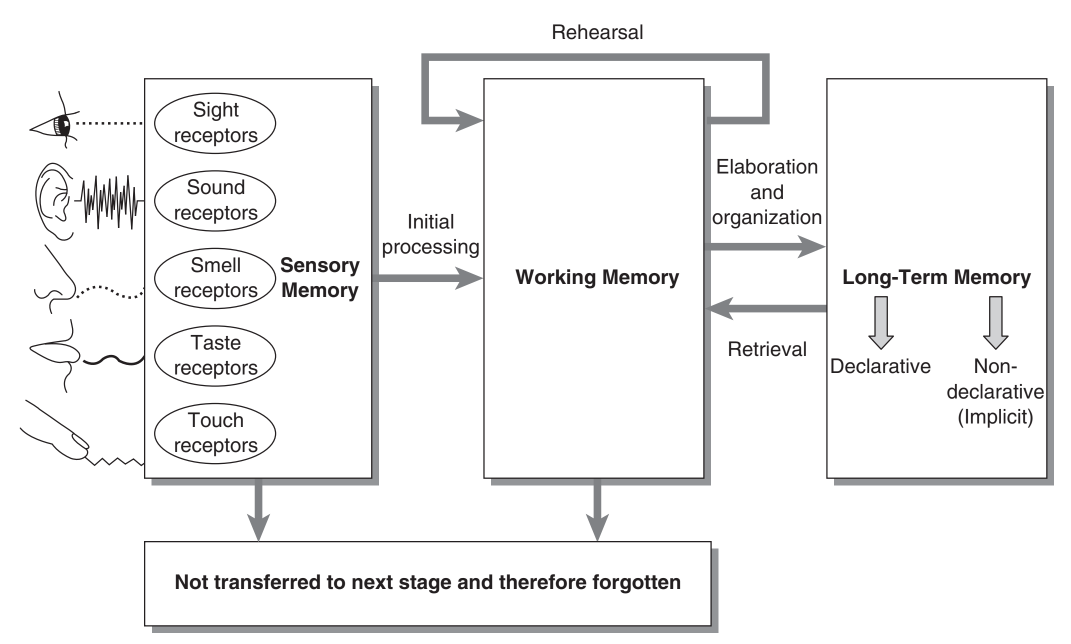
The structures in the brain related to sensory memory also determine whether or not we pay attention to incoming information. Our attention is focused by anything that the brain finds new, exciting, pleasurable, or threatening. In the classroom, we can capitalize on this by introducing information in new and exciting ways, making the learning experience enjoyable, and providing enough of a challenge to maintain the students' interest within a climate of low stress.

It is difficult to pay conscious attention to two things at once. We may think we can, but what we often do is rapidly cycle our attention from one thing to another. This effectively screens out a lot of sensory input. To illustrate this point, read the following paragraph (adapted from Wolfe and Sorgen 1990) and concentrate on the words in bold type.

Inductive teaching house **strategies involve the presentation** window **of a data set** door **from which the students** step **form categories,** house **generalizations and** window **concepts. The power of the strategy** door **is in the discussion** step **that takes place as** house **the students make** window **their decisions.**

What do you remember of the words in non bold type? They are, in fact, a series of words repeated over and over. Although you saw them and they entered your sensory memory, they were discarded because you were not paying attention to

Memory Processing Systems and Classroom Strategies



SENSORY MEMORY TO GARNER ATTENTION	WORKING MEMORY TO REHEARSE & ELABORATE	LONG-TERM ACCESS TO STORED MEMORY
Novelty **Relevance/meaningful** **Pique curiosity** **Emotion** • An interesting story • A question or problem • Pictures or video • A role play or drama • A unique object • A guessing game • A personal anecdote • A question • Focus on activities related to the standard	**Rote: for procedural memory** • Practice and recitation **Elaborative rehearsal** **Declarative memory** Using the new knowledge and skills in context • Mnemonics and memory pegs • Graphics/visual representations • Cooperative groups & structures • Simulations and role plays • Centers and projects • Using multiple intelligences • Problem-based inquiry • Performances & exhibitions • Raps, rhythm, song • Synectics • Integrated studies	• KWL • People search • Brainstorming • Carousel • Graffiti • Give one, take one • Yes, no, maybe • I have, who has? • Four corners • Journaling • 3-2-1 • Graphic organizers • Advance organizers • Think-pair-share

Figure 1.6

SOURCE: Parts of this illustration have been adapted with permission from *Building the Reading Brain* by Pat Wolfe and Pamela Nevills. Thousand Oaks, CA: Corwin Press, 2004.

them. We see this phenomenon in action when someone says, "You've got your head stuck in that book; you haven't heard a word I've said." In fact your ears did pick up the sound, but you didn't "hear" because you weren't paying attention. Similarly, people who live near highways filter out road noise. And, yes, hard as it may be to believe, students filter out their teachers.

The key point about sensory memory is that we are not consciously aware of the information processing that takes place. This is a crucial point for teachers, because students' attention will wander if they do not consciously select the information to which they should be attending. If they do not actively decide to concentrate on what the teacher is presenting, sensory memory takes over and selects what it finds relevant and interesting (Wolfe and Sorgen 1990). This is one of the reasons the lecture method may not be a particularly effective way of teaching. One thing we can do to make a lecture more effective is to stop every ten to fifteen minutes and allow the students to discuss the presentation's main ideas. This not only refocuses the students' attention but also helps them to understand the concepts being presented.

Short-Term, or Working, Memory

When information manages to capture the attention of the sensory memory, it is transferred into short-term memory. Information that does not capture our attention is discarded. Most people use their short-term memories to describe events from the past week, the past day, or earlier in the day. In the cognitive sciences, short-term memory is measured in seconds (Peterson and Peterson 1959).

Short-term memory sometimes is called the primary, or working, memory. Before you can begin to process information, it must be in your short-term memory. Think of it as your desktop. Unless the work is on your desk, you cannot begin to deal with it. This process of calling information into short-term memory is synonymous with conscious thought. When you consciously think about something, it remains in your short-term memory; when you stop thinking about it, the information either disappears or is transferred into long-term memory, where it is stored until you recall it at some other time.

Short-term memory can process a limited amount of material for a short time. Information fades quickly and is forgotten unless there has been enough impact or processing to transfer it to long-term memory. Without rehearsal or other forms of processing, information remains in short-term memory for less than twenty seconds (Peterson and Peterson 1959). Although this may seem short, it allows us enough time to process information without the added burden of remembering the details of every piece. For instance, it is enough time for most people to decode written text and to make sense of what they are reading.

Memory Spaces and Chunking

The other limitation of short-term memory is its capacity. It can handle only about seven separate pieces of information (plus or minus two) at one time (Miller

1956). To demonstrate this, read the following set of numbers, one time, and then try to recall them: 6324578.

You probably did quite well on that one. Now try another: 4785169657. This second set probably was much more difficult because it exceeded the capacity of your short-term memory.

Let's see what happens with another one. Read the following string of letters WTCFDNYSEPNYCUSA This string also exceeds the capacity of most people's short-term memories. However, if you group the information into chunks—WTC-FDNY-SEP-NYC-USA—it is much easier to recall, because there are now only five chunks. The fact that the chunks are well-known acronyms also helps in their recall,

Five chunks of information are well within the capacity of most people's short-term memories. Our retention of the jumbled list of letters may have been poor because the letters were seen as unrelated. When they were grouped, or chunked, we could handle them more easily. You also may have noticed a narrative thread, which has to do with events in New York City on September 11, 2001. This helps, because embedding information in a story or context aids in recalling it.

Information can be remembered in two ways: through rote learning or contextual learning. Of the two, contextual learning, or embedding, is the more powerful.

The way we create meaning by chunking information is neither random nor arbitrary. We do it by forming groups that make sense to us based on our previous experiences, which means that one person's way of forming chunks or categories may be different from another person's. Although they may be different, both ways of grouping are valid. Grouping information together in classes, categories, or chunks allows us to process greater amounts of information more easily.

Rehearsal

Making connections between separate pieces of information aids the formation of concepts or generalizations, which increases the probability the material will be transferred into long-term memory and made available for recall.

Although unrelated information disappears from short-term memory in less than twenty seconds, it can be held for much longer if it is given conscious and continuous attention. This process is called rehearsal. We rehearse information for two reasons: (1) when we need to retain it in short-term memory and (2) when we want to transfer it into long-term memory.

To understand the process of rehearsal for short-term memory, consider what happens when you look up a telephone number to order a pizza. You may rehearse by repeating the number to yourself until you have finished dialing. As soon as someone answers your call, you forget the number. If the number is busy, you may put the phone down and try again, but by this time you may have forgotten the number and might have to look it up again. However, if the number is important enough, or if you eat a lot of pizza, you may keep rehearsing it until it is transferred into long-term memory. This is an example of rote rehearsal.

Rote rehearsal is the capability of a person to retain information for extended periods in short-term memory, but it is not very effective in transferring information to long-term memory. When information learned through rote is transferred to long-term memory, it usually fades after a short time. Most of us have "rote memorized" information for an exam. How long did it last? For many of us, perhaps two weeks, but in some cases, we were lucky if it followed us out the door of the examination room.

Another form of rehearsal is called elaboration, or integrated rehearsal. It increases the probability that material will be transferred to long-term memory and held for significant periods of time. It does this by creating a context into which the learning is embedded.

Integrated rehearsal is the basis on which inductive teaching strategies work. Inductive learning means that students are encouraged to form concepts and generalizations from separate pieces of data through discussion. Inductive strategies, therefore, increase the probability that students will elaborate on what they already know by connecting new information to existing information.

Long-Term Memory

Among the capabilities of the human species is the ability to profit from prior experience and to plan for the future. This depends on two functions of long-term memory: information storage and information retrieval.

Information Storage

The storage capacity of long-term memory is, for all practical purposes, infinite. We have more capacity than we can possibly use in a lifetime. It also is hypothesized that information stored in long-term memory remains there indefinitely. We may not be able to recall much of this information, but it is there nevertheless. Because of the sheer volume of information, long-term memory is arranged and stored differently than short-term memory. Short-term memory is usually limited to seven separate pieces of information. This means that we can scan the pieces one at a time. Long-term memory holds so much information that scanning one piece at a time literally would take forever.

Theorists hypothesize that information in long-term memory is set up like a supercomplex filing system with the information chunked into categories and classifications. Long-term memory also has a cross-indexing system in which the individual files of information are elaborately interconnected. Furthermore, the system is continually updated as new information is integrated with existing knowledge. Every time we learn something new, the brain files it in the appropriate place. In fact, it stores the same information in a number of places as a backup system.

The sophistication and complexity of our "filing systems" give the brain its awesome powers to retrieve and process information. We all understand that the brain does not have a metal filing cabinet lurking about in the cranial cavity. But many people think that short- and long-term memory are specific places in the brain. Not true. Memories are not stored as pictures, which can be taken out and looked at occasionally. Instead, it is believed that the brain stores information in a number of different places: sounds in one place, sights in another, and color someplace else (Sylwester 1995). Whenever we wish to recall an event, the brain reconstructs it from the emotions, locations, sights, sounds, tastes, and smells associated with it. Each time, the sequence of recall may be different—smell before sound one time, color before smell another. This may be the reason that our recollections of an event often change over time.

We have the ability to recall information by delving into a number of files. In one instance, a particular sound may trigger the process of recollection; another time, a particular color may set in motion the process that reconstructs the same memory. As we recall one piece of the memory, it triggers another piece and soon we have retrieved the entire event.

We usually recall a piece of learning by remembering the context of emotions, sounds, smells, and locations associated with it. Information embedded in a context is stored in the same "file" as the context. This means that when we recall the circumstance (context) in which the learning took place, we also can recall the content of that learning. Location has a powerful effect both on the formation and the recall of memory.

As an example, when asked to recall what they had for dinner the previous night, most people first recall the location—I was at home or I was at a restaurant. Next, they recall the other people present—Elsie, Gran, and the kids. Finally, they zero in on their dinner plates and find the answer. Now, most people do not go around repeating, "Meatloaf, cabbage, meatloaf, cabbage," over and over, memorizing their dinners on the off chance that they will be held accountable. However, location has such a powerful influence on memory that once it is recalled, we are able to recall related information even though we did not deliberately try to remember it.

Classrooms and Long-Term Memory

In the classroom, we can capitalize on this by changing the location in which learning takes place (Jensen 1996). This might mean changing the seating arrangement, going to a different room, moving outside to sit under a tree, or going on an extended field trip.

We also can create a context for learning by engaging the other memory contexts—visual, auditory, tactile, and emotional. To do this, we might consider using masks and other props, performing role plays and dramatic presentations, telling stories, producing simulations, presenting analogies or metaphors, and manipulating concrete material, all of which tend to create a context for both learning and the formation of memories. By actively structuring multisensory experiences, we also can enhance learning in other ways. This is because these types of activities tend to alter learners' mental states by releasing endorphins that give rise to emotions such as joy, wonder, curiosity, and anticipation (Jensen 1996).

Barbara Given (2002) suggests that the brain uses five natural systems (Restak 1994) for attending and processing new information and skills.

- The emotional learning system (sense of cognitive and physical safety and well-being)
- The social learning system (sense of belonging and trust)
- The physical learning system (making sense through physical involvement)
- The cognitive learning system (engagement of the neocortex)
- The reflective learning system (metacognition and goal setting)

Given suggests that these are like theaters of the mind and the more "multiplex" the theaters are, the more senses that are tapping into the learning.

Because the connections between information stored in different parts of the brain are so comprehensive, we are able to process information very quickly; because each piece of information is connected with other pieces, we are able to make great leaps of insight and creativity. This leads us to the second capacity of long-term memory, its ability to retrieve and process information.

Information Retrieval and Processing

Another useful analogy to describe memory is an office that has an enormous filing system but only a very small desktop. Because the desk has limited space, we cannot have all the files out at one time. Therefore, we bring out the ones that we need to work with and leave the others in storage. When we have finished with one file, we put it back into storage to make room for another file to be brought to the desktop.

Although we may hold only seven pieces of information in short-term memory for a limited time, we can increase our memory's capacity by chunking the information into concepts. Short-term memory can hold seven facts or seven concepts. Seven concepts contain far more information than seven facts and, thus, we can increase the capacity of our working memory.

This discussion of memory systems may seem remote from the issue of student learning. However, if we are to proceed to higher-order thinking, such as comprehension, application, analysis, and synthesis, then our students need to be able to recall information and bring it on to their desktops before they can work with it. This is what learning is all about. It is a process whereby long-term memory is modified in some way. In other words, learning may be said to take place when new information is linked to existing or prior learning. If there are no links or hooks, no neural networks, to grab on to the information, it is lost and not learned. This is why the cramming of unrelated facts for an exam seldom has many long-term benefits. As soon as the exam is over, the information may be forgotten because it was not connected to prior learning in meaningful or useful ways.

Encoding Systems for Declarative Memories

People often use the term *memory* to describe or explain information they have stored over time. Neuroscientists refer to this as explicit or declarative memory. Declarative memories are formed in the hippocampus and then transferred to the temporal lobe of the cortex where they are stored for future use. When students answer questions or write exams, they are using declarative memory. Declarative memories come in a number of forms, all of which are encoded (i.e., processed and retrieved) in different ways. They include semantic or word-related memories and procedural or movement-related memories as well as episodic, automatic, and emotional memories (see also Sprenger 1999).

Semantic Memory

Semantic memory refers to the type of memorization associated with "book learning" or school learning. It is sometimes called *taxon* memory because it is used to recall lists, or taxonomies, of dates, names, places, and sundry other facts. It is word-related and tends to remember facts by seeking out associations, similarities, and differences among pieces of information and then chunking them together as groups of related ideas. It is the ability to associate or chunk ideas that allows us to recall facts more efficiently. Of all our information processing systems, the semantic memory is the least efficient and requires a high degree of intrinsic motivation. Despite this, it is the basis for many of the instructional strategies that schools favor most.

Episodic Memory

Episodic memory is sometimes called spatial or contextual memory because it is usually recalled by focusing on the context or event that caused the memory to be formed. Events that create a high emotional charge, such as the *Challenger* disaster or the events of September 11, 2001, are instantly and indelibly etched into our long-term memories by the release of a neurochemical marker that tells the brain, "This is important, remember it." Events that are less highly charged but perceived as novel, exciting, or pleasurable are marked in a similar manner and transferred to long-term memory with relatively small effort on the part of the learner. As in the example "What did you have for dinner?" we first recall the context: the location, the people, the smells and sounds. Once we recall the contextual information, the attached details are readily brought to mind. Episodic memory has a seemingly unlimited capacity and requires very little intrinsic motivation. However, instructional strategies that capitalize on this memory system, such as role plays, masks, and group investigations, are often regarded with skepticism by schools.

Procedural Memory

Procedural memory is associated with motor learning and is sometimes called muscle memory. Playing the piano, typing, and riding a bike are all skills in this category. The pathway to the formation of memories that allow us to perform complex physical skills involve the basal ganglia (which is located in the middle of the brain) and part of the cerebellum known as the motor strip.

The learning of physical skills involves the brain and the body in highly complex and integrated ways. This dual processing of information gives rise to extremely complex cognitive maps, which may be difficult to acquire, but once they are learned they are rarely forgotten. Learning situations that involve movement, such as conducting an experiment or building a model, require a greater variety of sensory input than do activities that involve only paper and pencil. As Robert Sylwester (2000) reminds us, we are a body/brain system:

> This suggests that it is also important to think beyond multiplicity in intelligence. Most body/brain systems are multiple. We obviously have multiple sensory/motor systems, and we now know that we have multiple emotional and attentional systems. We have known for some time that we have multiple memory and problem-solving systems. What we have is a multiple-everything bodybrain, and intelligence is only one part of the quite intricate equation. (p. 13)

Active learning situations are therefore remembered as being enjoyable and are recalled with a wealth of ancillary information attached to them. Procedural memory has an unlimited capacity and requires only moderate intrinsic motivation. Yet hands-on experiences are often regarded as frivolous and a waste of time unsuited to academic learning in many schools.

Automatic Memory

Automatic memory is a relatively recent discovery that is sometimes equated with conditioned response because a specific stimulus always triggers the same reaction. If you learned your multiplication tables in elementary school, you have already stored up a number of automatic memories. The equation 9×8 always triggers the same answer, 72. The alphabet, the rules of grammar, and the words of songs are all stored in automatic memory along with any other information that was learned through repetition or drill.

Automatic memory is often the key that opens up pathways to other types of memory. A song from our teenage years sometimes opens up episodic memories of summer days and the procedural memories of beach volleyball. The process then may lead to a list of names of all the players involved, which is stored in semantic memory.

The endless drilling of "facts and nothing but the facts" has gone out of fashion. However, certain pieces of factual information are crucial to all learning. For example, students who have not been drilled in number facts are always at risk in math. Students who cannot decode words are similarly hampered with regard to reading. Teachers must become more selective about the essential facts their students require and then, using rehearsal and repeated interaction with the information, ensure that these facts are acquired and understood.

Emotional Memory

Emotional memory is extremely powerful; it can override all other memories. Any experience with an emotional component, such as happiness, sadness, fear, or loathing, is processed by the amygdala, which is the emotional center of the brain. When an emotional memory is recalled, it may be strong enough to interfere with other memory systems, thereby causing the body to go into survival mode. This mode triggers the release of stress hormones and sundry other chemical messengers. In extreme cases, these may interrupt the brain's information processing system and render learning all but impossible.

Figure 1.7 lists some instructional processes that capitalize on the different ways in which the brain forms and encodes memories.

Instructional Processes Suited to Particular Memory Pathways

Semantic	Episodic	Procedural	Automatic	Emotional
• Graphic Organizers • 3 Step Interview • Jigsaw • I have . . . who has • Mnemonics • Acronyms • Acrostics • Raps, Songs	• Cooperative Groups • Role Plays • Props/Costumes • Bulletin Boards • Room Location • Case Studies • Simulations	• Practice • Rehearsal • Debate • Role Plays • Dance • Raps, Songs	• Word Association • Drill • Cues • Mnemonics • Poems, Rhymes	• Music • Personal Anecdotes • Experiences • Empathy Encouraged

Figure 1.7

The Brain Learns by Recognizing and Constructing Patterns

As we have seen, the brain can increase the capacity of its short-term memory by chunking facts and creating concepts. It does this by engaging its pattern-seeking abilities.

Caine and Caine (1994) noted that we make sense of the world around us by recognizing and constructing patterns. All new information is compared with these patterns to see if it matches with what the brain already knows. We are genetically programmed to seek patterns in the world around us—patterns in nature, patterns of behavior, patterns of speech, patterns in numbers and symbols. These patterns form the concepts, or mental maps, we use to organize and make sense of information in both formal and informal learning situations. The brain learns by constantly updating its mental maps. New information is integrated with previous learning to form larger and more complex mental maps. If the information doesn't make sense, it is discarded. If no previous map exists, then the information has no place to go and the brain goes about creating a brand new map.

This is similar to setting up a filing system to accommodate a new category of learning. Opening a new file or creating a new mental map is much more difficult than adding information to an existing file, which is why totally new concepts are usually hard to grasp at first. Part of the learning process, then, is about creating new maps.

Mental Maps

To visualize mental maps, picture a table on which a vast array of maps is displayed in an apparently random manner. Some maps are large and complex and others are small and simple. Some maps touch at the edges, others are in layers on top of one another. Now, imagine that the roads, rivers, and railway lines on these maps begin to grow and connect with similar features on other maps. This enables the maps to communicate with each other and share information. This networking of information is what complex learning is all about. The more complex the information on the map and the more profuse the connections to other maps, the more meaning we are able to derive from the learning.

In reality, a mental map is a network of neurons linked by synaptic connections. Each time we learn something, a series of new connections is made.

Once a connection has formed, it remains open for use as a conduit for long-term memory or other kinds of learning. Every time the connection is used, it becomes stronger, which makes it easier for neurotransmitters to bridge the synaptic gap and pass their message on to the next neuron in the chain. Rehearsal, repetition, and elaboration of new learning strengthen neural connections and thus make recall and further elaboration of learning easier.

Pattern Recognition and Probability

Another advantage of the brain's ability to recognize and construct patterns is that it allows us to make decisions quickly and flexibly on the basis of probability. This allows us to recognize a pattern, make rapid and efficient judgments, and come to an appropriate decision quickly, often before all the evidence is in. For example, the human face is a pattern. The ability to recognize faces is a survival behavior, which allows us to recognize friends and identify potential foes instantly. For most of us, this is a simple task and yet computers have a great deal of difficulty with it. Computers have individual processors that allow them to manipulate huge numbers in a fraction of a second; however, they have only recently begun to recognize faces, and some forms of disguise still confuse the average computer.

We have billions of processors and, although ours are slower and fuzzier than a computer's, the sheer number and complexity of our connections allow us to identify patterns very quickly. Computers have to work out every detail before making a decision; the brain does this based on previous experience and probability. As far as the brain is concerned, if someone looks like Aunt Gladys and walks like Aunt Gladys, it's probably Aunt Gladys. The brain jumps to this conclusion even when Aunt Gladys is wearing a Halloween costume and a false mustache. The computer, on the other hand, would focus on these details and would search its memory banks for information about people with mustaches and costumes. Not only would this take a long time, it is doubtful the computer would identify Aunt Gladys correctly.

Sometimes, the brain jumps to the wrong conclusion, but generally it does very well. For example, good readers do not sound out every word and examine every letter before deciphering a page of text. To do so would overload the working memory's capacity to handle information. When we read, our eyes scan up, down, and across the page looking for patterns in the form of context and syntax clues. These chunks of information are enough "probable cause" for the brain to make sense of the text. For example, the statement *The man ran his car into the garage* makes sense based on most readers' previous experience. However, the statement *The man ran his car into the garbage* is more unusual, and the reader might not grasp the accurate meaning at first. The brain then would scan the following lines of text and read *and it spilled all over the sidewalk.* Now, the reader detects an anomaly in the pattern of information and revises his or her previous conclusion.

There are a number of implications here for how we design curriculum and present information to our students. Schools are one of the few places where information is compartmentalized into subject disciplines. In the real world, most information comes at us as an integrated whole and we are able to deal with it. In schools, conventional wisdom dictates that we break learning into small, bite-sized pieces, or manageable chunks. This sounds plausible, but if we don't make explicit connections between these bite-sized pieces and expose students to the overall pattern, it should not surprise us when they "don't get it."

The mind is programmed for survival in a complex world where data are delivered as whole chunks of integrated information (Jensen 1996). In natural learning situations (as opposed to structured learning situations), the information is not broken down into specific bits, and yet we are able to cope with it. When schools oversimplify or apply a rigid structure to the teaching-learning process, they may inhibit the natural working of the mind and restrict the students' ability to learn (Jensen 1996).

Parallel Processing

The human brain is capable of handling enormous amounts of information simultaneously. This is called parallel processing. The ability of the brain to process information down multiple paths, using multiple modes simultaneously, is what gives us our enormous capacity for detecting patterns and forming mental maps. For example, sights, sounds, and smells may combine to provide information that is processed in various parts of the brain and then cross-referenced to see if it conforms to previously acquired patterns. Based on this information, the brain makes decisions about what action to take.

The linking and cross-referencing of information simultaneously along multiple pathways is what allows us to learn, gain understanding, and make decisions. On the other hand, processing information along one path at a time produces very few insights or moments of discovery when the person says "Aha."

To picture both linear and parallel processing, imagine a large multinational corporation with a worldwide network of interconnected businesses. The company has a chief executive officer (CEO) who is responsible for running the company and a team of advisers from each business unit who provide various kinds of information, such as financial, legal, geopolitical, security, and technological. The advisers report directly and individually to the CEO, who, based on their input, makes all executive decisions. This is an example of linear processing, an often slow and cumbersome process.

An alternative would be for the advisers to report to the CEO as a group, in a somewhat chaotic free-for-all, with no formal agenda, and with each adviser vying for the CEO's attention. The CEO receives, links, and cross-references the information, assigns meaning to it, and decides what to do with it.

This simultaneous, or parallel, processing of information is more aligned with how the brain operates. In real terms, much of the information that goes into making a decision is below the threshold of the conscious mind and thus we are unaware of it. However, once a decision is made, it quickly captures our attention.

Parallel processing may appear to be somewhat random and chaotic, but it is very fast—and it works. Parallel processing allows the brain to receive information, sort it, and make decisions quickly, thus enabling an individual to learn quickly and effectively.

Learning through parallel processing works very well, but it is somewhat "messy." The acquisition of knowledge and skill is different for all of us and is, for the most part, nonlinear and somewhat disorganized. Learning often is recursive, which means that we appear to be covering the same ground over and over as we grope our way toward understanding. One thing is certain. In the thinking-learning process, the journey from point A to point B is rarely a straight line, and each of us may take a different, winding path to get to a similar destination.

Complex Learning and the Brain

As teachers, we need to be aware that what appears logical and simple to us may make absolutely no sense to our students. This is especially true when we break the information into smaller pieces and then deliver the pieces in a logical progression. The students may not have the neural networks in place that allow them to make sense of the small, unconnected bits of information, and the progression may be logical only to the teacher. This is why activating prior learning at the start of any lesson is beneficial—it allows the teacher to find out what the students know, and it enables the students to bring information up to the level of conscious thought, or working memory.

The second part of any lesson should be devoted to "painting the picture on the box." The teacher does this by telling the students where the current lesson is going and how it is connected to previous lessons. Just as assembling a jigsaw puzzle is difficult when one doesn't have the picture on the box, learning is difficult when students have no idea how the pieces fit together.

We are genetically programmed to make sense of complex situations, because much of our learning is survival oriented. The real world is complex, and information comes at us in integrated chunks delivered at breakneck speed. To survive, we have to perceive patterns quickly, weigh them, take action, and store the information for future use. Fortunately, the evolutionary process has made us good at this type of learning.

First Language Acquisition

Acquisition of a first language is a prime example of the brain's ability to thrive and make sense in complex environments. Learning to speak is a survival skill, and young children genetically are predisposed to learn a language. In fact, huge numbers of brain cells are designated solely for this purpose. During the learning process, children are bombarded with a variety of sounds that are rich, random, and for the most part, unorganized. Some of these sounds are in the form of language, but if we listen to the ways in which most adults communicate with young children or the ways in which children communicate with each other, we may realize that this is hardly a structured learning situation. From this complex stew of input, children eventually establish patterns and make sense. Contrast this with the way in which many teachers "teach" a second language by breaking it into logically sequenced bits. This seems contrary to the way in which the brain learns best. Have you ever wondered why all but the most severely mentally handicapped can acquire a first language, but many of us have great difficulty learning a second language . . . in school?

Many teachers think that the most successful language teaching takes place in immersion programs in which students are bathed in the language for significant periods of time during the day. Through a process of unconscious and conscious learning, they begin to perceive the patterns and structures on which the language is based. They then form responses based on these patterns, and within a relatively short period of time, they are able to communicate in the new language.

The brain has an enormous appetite for information, but it also has difficulty with information that is delivered at the slow, measured pace of the classroom. Many people seem to learn best when they are immersed in highly complex activities. For example, many students seem to thrive on sports, drama, field trips, concerts, and other multisensory, real-life learning experiences. In these types of activities, the information is not prepackaged, linear, or sequential, and students do these activities with their friends, which provides a social context for learning that makes the events more pleasurable and thus more appealing to the brain.

Learning Is a Function of Experience

Traditional theories of intelligence are based on the assumption that the level of intelligence and, hence, of learning potential is fixed at birth and is, for the most part, incapable of being changed for the remainder of life. Work by Marian Diamond (1988) at Berkeley and Howard Gardner (1991) at Harvard refutes this notion. They claimed that if we know and understand how the brain learns, then we can assist learners to capitalize on their brains' capabilities.

It has been postulated that although the genetic blueprint for a human being contains billions of pieces of coded information, in terms of brain development, there is only enough information to lay down the "hardware" and the "operating system" and load up the "applications." The hardware is the brain. The operating system includes reflex behaviors that are "hard-wired" into the brain and allow the organism to get up and running. The applications are neural networks that give us the potential to learn, just as applications give the computer its potential to do a wide variety of tasks, such as word processing, number crunching, and graphic design.

According to some theorists, notably Edelman (1992), the brain has all its capabilities in place at birth. However, it is the activation of the neural networks by "experiencing" the outside world that results in the process we call learning. Imagine your parents have given you a computer that has been loaded with software programs for every use imaginable. There is a problem, however. They don't know which programs are in place. Neither do you, until you use them. It is possible, therefore, to have a superb graphics program loaded and ready to use but to be unaware of it. The software, therefore, lies dormant until it is activated. Similarly, a rich and varied set of experiences activates the neural networks and allows them to flourish; an impoverished set of experiences results in limited development.

Learning, therefore, results from the powerful interaction between the neural networks with which an individual is genetically endowed and the experiences to which the individual is exposed over the course of a lifetime (Sylwester 1995). One person may be genetically endowed with a superior piece of equipment, but his or her potential may be stunted by a paucity of experience; another person may be born with inferior equipment but overcome the disadvantage by being exposed to rich and varied experiences. For example, two people may work with the same word-processing program. One person may write the great American novel, while the other person might produce a laundry list.

Learning and the Growth of Dendrites

Diamond's work (1988) illustrates what happens when the brain is stimulated by a variety of experiences and a sensory-rich environment. Electrochemical processes release enzymes that initiate the construction of synaptic connections between the dendrites of one neuron and the axon terminals of another. Synapses are the connections that join individual neurons and make networks of neurons possible.

The development of synaptic connections shows a rapid growth between infancy and approximately age ten. After age ten, right up to old age, the brain has the ability to form new connections and "rewire" itself as a result of learning. It is the profusion and complexity of these connections that give the brain its capacity to recognize and construct patterns and perceive subtle differences.

To demonstrate the number of possible connections that a human brain can form, we could take ten items and combine them in every possible way. There are 3,628,800 possible connections. If we were to take eleven items, the number would jump to 39,916,800. If we were to take the brain's 100 billion neurons, each of which has 20,000 dendrites, and combined them in every possible way, we would have an astronomically high number, which indicates the complexity of our neural network systems.

The brain remains remarkably plastic, or modifiable, throughout life. It is capable of making new connections at almost any time from birth to death. Independent studies carried out by neuroscientists Marian Diamond (1988) and William Greenough (Greenough and Anderson 1991) show how an enriched environment and a variety of stimulating activities seem to be the key to this plasticity. Their experiments were conducted on rats, some of which were exposed to environments in which they were able to socialize with other rats and engage in exciting activities, such as wheels and mazes. The rats in the control group were isolated in cages and deprived of stimulation. While the control group showed little or no brain growth, the rats in the enriched environment had much denser brains. In fact, Greenough found that he could increase the number of brain connections by up to 25 percent by exposing the rats to highly stimulating environments.

Although Diamond and Greenough's work was conducted on rats in various combinations of enriched and impoverished learning environments, the same concept seems to apply to humans, as can be seen from the work of neuroscientist Bob Jacobs and his associates (Jacobs, Schall, and Scheibel 1993). In studying the brains of graduate students and high school dropouts obtained through autopsies, he found that the graduate students' brains had 40 percent more dendritic connections than those of the high school dropouts. He also compared the brains of graduate students who participated in highly engaging activities such as music, sports, and drama with those of their more sedentary counterparts. Like Diamond and Greenough's study of rats, he found that those who had engaged in stimulating activities had 25 percent more brain connections than nonparticipants.

Dendrite Growth and Enriched Learning Environments

For those teachers and parents who crave a return to the "good old days" when children sat in straight rows and recited, copied, rote-learned, and regurgitated the information to the teacher at exam time, consider this: Jane Healy (1990) stated that the minds today's children bring to school are different from those of forty years ago. The difference is accounted for by the variety of real-life experiences that children bring with them to school. In many cases, students of the 1940s and

1950s tended to be more actively engaged with the community, its workings, and its infrastructures. Many children played and learned in the streets, woods, and fields without the looming, albeit well-meaning, presence of adults and coaches. Their experiences were real, varied, and enormously engaging.

These hands-on, or concrete, experiences with the real world prepared the brain for learning. What may have seemed to be unstructured play had a very serious purpose. It allowed students to discover the underlying rules and patterns that organize and make sense of the world. This kind of informal, discovery approach to learning equipped students to deal with the abstract world of the school curriculum. In effect, it may have set up a filing system for the storage and retrieval of information.

By contrast, many of today's students are starved for real-life experiences. For approximately six hours a day, five days a week, they function in the abstract, symbolic environment of the classroom, where experiences are often far removed from the real world. Then, they may spend an additional two to four hours glued to the television screen at home.

Television and Dendrite Growth

Television is a poor replacement for real hands-on experience and, in fact, may be contrary to the ways in which the brain is genetically disposed to learn. When children watch TV prior to age six, they are doing the opposite of what their brains are required by nature to be doing—that is, become actively engaged with the real world in a hands-on, interactive way. For most children, this problem is compounded by their lack of experience and knowledge to interpret what they see on the screen.

This can be compared to presenting a postgraduate-level video on quantum physics to a room full of adults, all of whom have different backgrounds and levels of education. Each person will derive meaning from the information based on prior experience and patterns of learning. But if there is no prior experience with which to interpret the program, the information has no place to go. The brain then has to learn a new vocabulary and set up a filing system for the new information. The more practice one has with a wide variety of learning experiences, the easier this becomes because there are more neural pathways available to begin constructing the new file. Learners with a wide range of experiences often have better problem-solving skills because they have more ways of recalling and connecting information to use in their search for solutions. In other words, they have learned how to learn.

For those without a wide range of experiences, the process of learning something new is hard work. The brain seems to learn best when it is allowed to use its potential for parallel processing. This means that information is taken in by all the senses simultaneously and processed by the brain to arrive at the most plausible meaning. Parallel processing tends to extend and strengthen neural networks, because each sensory input codes and stores information in different ways and in different parts of the brain. When these pieces of information communicate with each other, we experience a kind of synergy that amplifies our understanding.

Television, unlike interactive, concrete learning, provides input through only two senses—vision and hearing. This kind of information is processed in the posterior regions of the brain and may remain unconnected to other neural networks. In terms of brain development, the phrase "use it or lose it" is very applicable, and neural networks that are not used tend to shrivel up through a process called pruning. Thus, it appears that television may, in fact, stunt the neural basis for learning, especially in young children (Burns 1991). The passive reception of information, without discernment or thinking, requires no particular response and seriously undermines the ability to learn about and interact with the environment.

In comparison, television programs that provide interaction and encourage responses from young viewers promote thinking because responding to questions and paraphrasing the performers' comments require a certain level of comprehension. For example, the success of Fred Rogers (in *Mr. Rogers' Neighborhood*) most likely is because he elicited a response from his viewers: "Boys and girls, can you say the word accelerated particle? Ah, knew that you could."

When we combine the abstract, symbolic programs of many schools with the passive consumption of television in the home, we are creating an environment that is incompatible with how the brain learns best. In effect, a child's whole day may be lacking in the concrete experiences needed to provide hooks and connections for higher-order thinking and abstract learning. In teaching, we need to explore concrete examples before moving to abstract learning.

Growing Dendrites

The need for concrete examples is the reason a field trip to the Pioneer Museum might be useful before starting a teaching unit on pioneers. In this way, the students actually see, touch, and experience butter churns, apple peelers, and root cellars before dealing with them as abstractions in class. Similarly, in science, we might proceed from the concrete to the abstract by allowing the students to perform an experiment before discussing the related concepts. Talking about sublimation, precipitation, solids, and gases makes much more sense if the students have actually experienced the process and made their own observations. Hands-on, active learning facilitates the formation of neural connections much more readily than learning concepts from a purely abstract viewpoint. If the teacher actively conducts the experiment while the students passively watch, whose neural networks are getting a workout?

IN CLOSING

During recent years, many people have been reconceptualizing their understanding of the brain and how it engages in the process of learning. Recent interpretations suggest that the brain may be more like a jungle than a computer, or it may be like both. The brain is infinitely complex, somewhat disorganized, and definitely nonlinear. The whole-brain approach to learning is beginning to replace the older compartmentalized models in which certain functions were isolated in specific parts of the brain. Many people now believe that all parts of the brain are highly interconnected and involved in the process of learning.

As teachers, it is useful to understand the emotional component of all learning and the part it plays in creating classroom climates that support learning. We also need to be aware of the ways in which emotions focus our attention and the role they play in the formation, retention, and retrieval of memories.

The rich interconnection of our neural networks gives the brain its powers to recognize and construct patterns. Anything that we can do as teachers to promote this pattern-seeking ability constitutes a brain-compatible strategy. These strategies include making explicit connections between concepts or, better still, providing opportunities for the students to make their own connections by engaging in discussions and activities that promote concept formation and comprehension.

All learning is survival oriented. The brain attempts to make sense of the world by attaching meaning to whatever it encounters. At birth, the neural networks that give us the potential to survive as well as to perform complex tasks are already in place, but they seem to be activated only when we are exposed to experiences that bring them into play. Schools, therefore, need to provide a rich variety of experiences that activate students' brains. This is compatible with the brain's genetic disposition to thrive on complexity and to use a multisensory or parallel processing approach to derive meaning from complex situations. Therefore, the most favorable learning activities to activate neural networks are those that are complex, engage a variety of the senses, and are perceived by the learner as being novel, emotionally engaging, relevant, and useful.

Reflections

Take time alone or with a study group to consider the "Brain Bits" and discuss or write down ideas on supporting or implementing them into your classroom or school.

7 Brain Bits	**So in my classroom/school . . .**
Students need a safe environment	
Relaxed alertness is a preferred state - "High challenge and low threat"	
Emotions have an impact on learning	
Social relationships are important	
The brain seeks patterns, meaning, and relevance	
Active learning and enriched environments grow dendrites	
We have many memory pathways	