# Part I

## Physiology and Brain Science

# 1 Brain Science

## THE BRAIN IS THE UNIVERSE WITHIN

*She's a brain! You're a numbskull! That's a harebrained idea! Have you lost your mind? Are you out of your mind? Put on your thinking cap. Use your noodle. I'm having a brain drain. Use your gray matter. I think I'm brain dead today. It's an idea that is swirling around in my mind.*

These are just some of the remarks one hears in everyday references to the brain and the mind. In fact, these sayings offer concrete evidence for the common understandings people have, and have had for some time, about the human brain. Yet with the avalanche of information available through brain imaging technologies, interest in the brain is on the increase. As brain research explodes following what was known as the Decade of the Brain (Klein, 1997), parents, teachers, educators, and students themselves are now genuinely intrigued with the emergent knowledge of how their brains remember and learn.

## HOW TO BE A CRITICAL CONSUMER OF RESEARCH ON THE BRAIN AND LEARNING

There is reason to be cautious and considered when reading and pondering ideas that are emerging about the human brain. *Brain science, brain fiction* is how Bruer (2002) refers to this fascination with research on the brain and learning. He has been the dissenting voice in the field, cautioning educators that it is far too early to make direct connections between research findings on how the brain learns and implications for teaching and learning. He specifically discusses and offers insightful comments about three big ideas: (1) in the early years of life, neural connections form rapidly, but we don't know if neural branching offsets neural pruning; (2) critical periods occur in development, but this may be a "myth of the first three years," as he calls it in the title of his book, because people seem able to acquire culturally and socially transmitted skills such as reading, mathematics, and music at any age; and (3) enriched environments have a pronounced effect on brain development, but our appeals to this research are often naïve and superficial, as neuroscience says nothing, really, about which environments are more or less enriched than others.

To be fair, in response, Wolfe (1996, 2001) argues with Bruer (2002) that brain/mind research supports sound pedagogy, as Brandt (1988) argues that educators need to know about the human brain and that it is not too early to search for the implications for education. While both Wolfe and Brandt rebut Bruer's view, it seems prudent, as consumers of current and ongoing information about brain physiology and brain functioning, that readers consider both sides of the issues whenever possible. Bruer provides a needed service by playing the devil's advocate, and readers need to seek out his writings as well as other dissenting voices. By reading opposing viewpoints, educators are forced to become more discerning consumers of cognitive and neuroscience research findings.

## JUST THE FACTS! WHAT ARE THE FACTS ABOUT THE BRAIN?

Scientists have discovered numerous facts about the 100 billion nerve cells, called *neurons,* that make up the organ that is the human brain. This unique organ is protected by the cranium, or skull. The average brain weighs approximately three pounds (one and a half kilograms), is about the size of a small grapefruit or a cabbage cut in half, appears wrinkled like a walnut, and feels somewhat like a ripened avocado.

While the brain accounts for only 2 percent of a person's body weight, it uses 20 percent of the energy in the body and generates 25 watts of power (enough energy to illuminate a light bulb) when a person is awake. Messages travel within the brain through 30,000 miles of neural connections in the cerebral cortex at speeds of up to 250 miles per hour, and several billion bits of information pass through your brain each and every second of your life.

The study of the brain is considered science—biology, neurology, biochemistry, or neurochemistry—while the study of the mind is considered psychology or cognitive psychology. Both the neurobiological evidence and the cognitive-psychological findings offer scientists and researchers a better understanding of the brain and the mind and of their inner workings. While most educators are interested in how the mind works and what they can do to enhance learning, knowing how the brain itself works is an important prerequisite in shaping what is referred to here as *brain-compatible classrooms*: classrooms in which the teaching-learning process is structured to parallel the ways the brain obtains and retains information (Sousa, 2000; Wolfe, 2001).

To begin, let's focus on the brain and what is known about this amazing organ. Read the statements in Figure 1.1 and either agree or disagree with them in terms of your first thought or intuition. Then review the discussion comments immediately following the list of statements in Figure 1.1. Be aware that there are often differing opinions on these issues. They are presented here to stir up your prior knowledge about the brain and how it functions. This interactive reading is intended to precipitate a robust discussion about the human brain.

1. The brain is more like a sieve than it is like a sponge.
2. Critical periods (windows of opportunity) are not that critical.
3. Enriched environments grow dendrites.
4. Humans use only 10 percent of their brains.
5. The brain and the mind are one.
6. Memory is stored throughout the brain and must be reconstructed.
7. Brains are as individual as fingerprints.
8. Nurture rules over nature in brain development.
9. Experience affects how the brain is organized.
10. Our brains are plastic.
11. Alcohol kills brain cells.
12. Reasoning rules over emotions.
13. The brain "rewires" itself.
14. Male and female brains are different.
15. Music enhances general cognitive abilities.
16. The brain is not that much like a computer.
17. The brain is like a jungle ecosystem.
18. Pruning is a process that occurs in teenage brains.
19. "That added a wrinkle to my brain" means you just aged.
20. The brains of identical twins are not identical.

**Discussion of the Statements**

**1. The brain is more like a sieve than it is like a sponge.**

The brain is more like a sieve because it is designed to let go of information that is not important. It chunks information as it searches for connections that help keep the information in the sieve. The brain pays attention when the input is novel, relevant, or meaningful. Think of the implications for teaching . . . and the need for getting the attention of the learner.

**2. Critical periods (windows of opportunity) are not that critical.**

While there are sensitive periods when the brain seems more ready to learn some things, such as language and vision, the brain is able to learn those things beyond what is considered the sensitive period (Bruer, 2002).

**3. Enriched environments grow dendrites.**

Diamond and Hobson's (1998) *Magic Trees of the Mind* demonstrates the changes in the growth of dendrites when exposed to enriched environments. A key to this enriched environment with children is time to engage in that environment (Wolfe, 2001). It's not just about having a lot of stimuli.

**4. Humans use only 10 percent of their brains.**

Neuroscientists consider this idea a myth. If this were the case, the brain would compensate easily when damaged. However, some cognitive psychologists suggest that humans do not use the full power of their brains/minds, which might be where this 10 percent idea comes from (Gardner, 1999b).

**5. The brain and the mind are one.**

Scientists often say, "Yes, the brain is the brain is the brain is the brain." Psychologists often say, "The brain is physiological, the mind is psychological; the brain is the hardware, the mind is the software. They are different." Be aware when reading about the brain/mind and the language used. Think critically about authors' perspectives. Are they talking science or psychology? Do they use the term *brain* or *mind?*

6. **Memory is stored throughout the brain and must be reconstructed.**

   Yes, it is now believed that memory is stored throughout the brain and is reconstructed in the mind. Different types of memory lanes are available to sort memory and to spark memory reconstruction. Memory is the only evidence we have of learning, according to Sprenger (1999).

7. **Brains are as individual as fingerprints.**

   Yes, this is generally accepted. Each brain has its own unique wiring based on genetic codes and life experiences; each has a jagged profile of intelligences, according to Gardner's *Frames of Mind* (1983) and *Intelligence Reframed* (1999b).

8. **Nurture rules over nature in brain development.**

   This points to the nature-versus-nurture question about brain and intellectual development. It is generally accepted that both are responsible, not one or the other (Sousa, 2000; Wolfe, 2001).

9. **Experience affects how the brain is organized.**

   Yes, the organization of the brain is impacted by the environment. Read *Inside the Brain,* by Kotulak (1996).

10. **Our brains are plastic.**

    The concept that the brain is dynamic and ever changing, continually forming new neural networks and pruning dendrites that are not being used, is called *plasticity* (Diamond & Hobson, 1998; Kotulak, 1996).

11. **Alcohol kills brain cells.**

    Alcohol can cause extensive damage to the fetal brain, causing fetal brain syndrome. It is unclear whether alcohol kills brain cells in developed brains (Wolfe, 2001).

12. **Reasoning rules over emotions.**

    Emotions seem to hijack other systems in the brain and take over momentarily. But cognitive functions may be alerted through signals from the emotions. There seem to be visceral reactions that cue the cognitive functions (LeDoux, 1998).

13. **The brain "rewires" itself.**

    There is much evidence that the brain does rewire itself based on the experiences it has through sensory input of all kinds. Again, Kotulak's (1996) book *Inside the Brain* is one resource. Another is Diamond and Hobson's (1998) *Magic Trees of the Mind.*

14. **Male and female brains are different.**

    Emerging evidence seems to show that male and female brains are physically different and that there are additional differences in how they process information. For example, the corpus callosum appears larger in female brains. In terms of processing information, the female brain seems to process language earlier and more easily, while male brains seem to process spatial information more readily (Sousa, 2000).

15. **Music enhances general cognitive abilities.**

    While there is little real proof of what is termed the Mozart Effect (the idea that playing the music of Mozart will increase cognitive functioning), there seems to be some truth to the idea that music in general enhances cognitive abilities with more focus and concentration (Jensen, 1999).

16. **The brain is not that much like a computer.**

    According to Sylwester (1995) and others, the brain is not as neat and tidy as the computer analogy suggests. In fact, in studies of artificial intelligence, scientists are not able to simulate the complexity of connections and problem solving that occurs in the human brain.

17. **The brain is like a jungle ecosystem.**

    Edelman (cited in Sylwester, 1995) uses the analogy of a jungle ecosystem as a more apt description of the human brain in appearance and growth of dendrites.

**Figure 1.1** *(Continued)*

(Continued)

**18. Pruning is a process that occurs in teenage brains.**

The brain does experience pruning at various times throughout life. Early adolescence seems to be a time of great pruning as the brain matures (Wolfe, 2001).

**19. "That added a wrinkle to my brain" means you just aged.**

There is a saying that when someone learns something or realizes an insight, the learning experience adds a wrinkle to the brain, meaning the brain grew bigger and had to wrinkle up more to fit under the skull.

**20. The brains of identical twins are not identical.**

The brains of identical twins are not identical because the twins have different sets of experiences that cause the brain to rewire accordingly. This is an example of the nature-versus-nurture argument. Both affect the brain: on the nature side, genetic makeup affects the brain; on the nurture side, learning is a function of experience (Wolfe, 2001).

**Figure 1.1** The Human Brain: Agree/Disagree Discussion

# MACROVIEW: A LOOK AT THE EXTERIOR OF THE HUMAN BRAIN

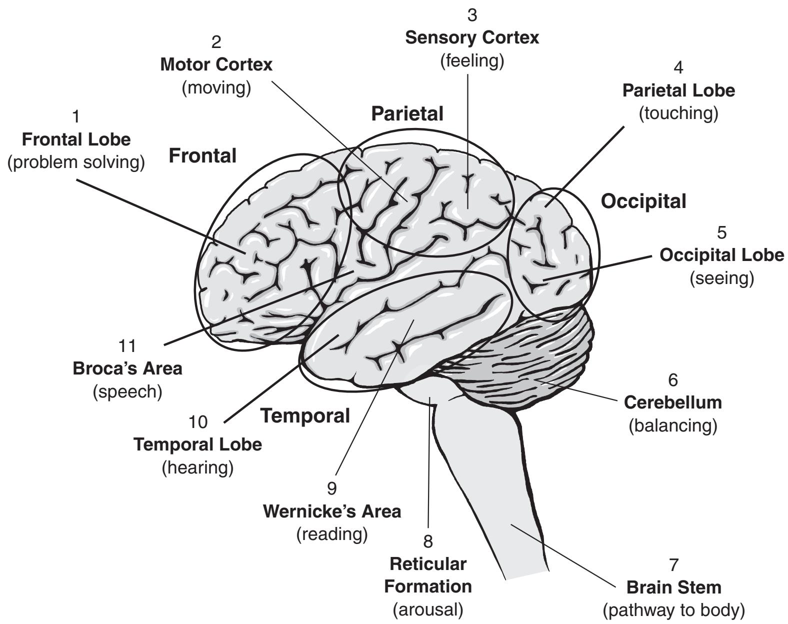
In an attempt to clarify and simplify the physiology of the brain, this discussion is divided into two parts: a look at the exterior of the human brain and a look at the interior of the brain. While this serves as an organizing principle for the discussion, it also presents some ambiguities. It is not an exact division of the exterior and interior of the human brain. Yet it does provide a way to read and understand complex information about the physiology of the brain.

## Geography of the Human Brain (Topography)

Sometimes a visual helps anchor abstract ideas. To provide a big-picture look at the brain, Figure 1.2 depicts a general geography of the human brain. This is a grossly simplified version, but it does represent major areas and the accompanying functions of those areas.

To continue this discussion about the exterior brain, it is important to know that the neocortex is much larger than any other part of the brain. It has six complete layers of tissue and 30,000 miles (48,280 kilometers) of neural fibers. In fact, to more accurately represent the brain in terms of proportions, a simple model can be created using your right index finger, your left hand, and six sheets of newsprint. Simply hold up your right index finger to represent the brain stem (see Figure 1.3). Next, place your left hand over the right finger, forming a crescent (about the size of a bagel) to represent the interior limbic area. Finally, take the sheets of newsprint and crumple them up to fit as the neocortex over the brain stem and the interior limbic area. This physical model helps novices envision a mental model and gives a more accurate image of how big the neocortex is compared to other parts of the human brain.

The brain stem governs automatic functions of the body such as digestion, heartbeat, breathing, sneezing, and coughing. In addition, research favors the




**Geography of the Brain**

1. This frontal lobe is future oriented and thinks creatively and analytically in a problem-solving mode. It also takes part in the complex behaviors called personality.
2. The motor cortex governs movement and overall motor control. It is seen as one of two distinctive channels in the neocortex.
3. The sensory cortex involves sensory input and appears as the second channel in the neocortex, near the motor cortex region.
4. The parietal lobe, located at the top of the brain, is often associated with touch and the sense of feeling received from all over the skin. It senses hot and cold, hard and soft, and degrees of pain. It also senses taste and smell and helps to integrate the senses.
5. The occipital lobe, located in the hind brain, at the base of the skull, rules over vision and the ability to see and observe. It works out shapes, colors, and movements and is the site center of the mind's eye.
6. The cerebellum, also part of the hind brain, is the center of balance for the human body. It coordinates movement as it monitors impulses from nerve endings in the muscles. The cerebellum is part of the memory system and retains muscle memory. It is believed to hold procedural memories that are part of step-by-step methodologies such as problem solving.
7. The brain stem, located at the back of the brain and extending to the spinal column, is the brain path to the body. It is the center for sensory reception and monitors vital bodily functions such as heartbeat, breathing, and digestion.
8. The reticular formation, located on the brain stem, is the trigger for arousal. It integrates the sensory information into a general level of attention. It acts as a chemical net that opens and closes to the incoming information flow.
9. Wernicke's area, located in the left temporal lobe, is considered the center of reading in the language region of the neocortex.
10. The temporal lobe in the neocortex, located above and behind the ears, is the center for hearing and auditory impact. It receives auditory signals and identifies sounds by comparing them with sound patterns in the memory banks.
11. Broca's area is the center for speech in the neocortex and relates to other language areas of writing and reading.

**Figure 1.2**

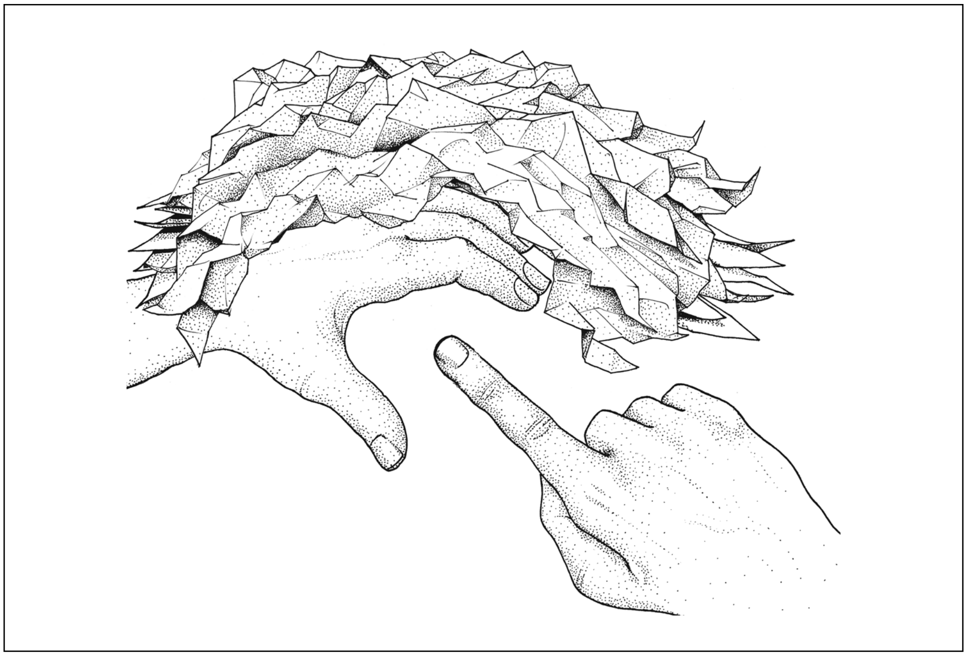


**Figure 1.3** Brain Simulation

idea that the emotional functioning of the brain probably occurs throughout the entire brain, not simply in the limbic area. While the amygdala seems to govern some part of the emotions, LeDoux (1998), a widely respected expert in the area of emotion research, prefers to cross-categorize emotional functioning as processes that occur collaboratively with other brain areas.

The six sheets of newsprint in our physical model of the brain represent the massive amount of brain area designated to higher cognitive functions in the neocortex. This is where humans solve problems, make decisions, and do all kinds of critical and creative thinking.

## Three Views of the Brain

To further illuminate a big-picture understanding of the human brain, three distinct views are offered for review: top to bottom, front to back, and left to right. Each view presents a slightly different perspective for consideration within the big-picture view.

### *Top-to-Bottom View*

This view somewhat parallels MacLean's (1969) early image of the triune brain theory. Figure 1.4 depicts the top-to-bottom view of the brain. The top, or neocortex, is the outermost layer of the brain (the cortex, which means bark, constitutes four-fifths of the entire brain; Sylwester, 1995). This top layer is often referred to as the *thinking brain* because all higher-level cognitive functions happen in this folded section of the brain.

Moving from the top layer down, the middle section of the brain, or the limbic area, is key in the control of the emotions. It is part of the *feeling brain,* and it signals the body to receive or express emotions, to accept or reject

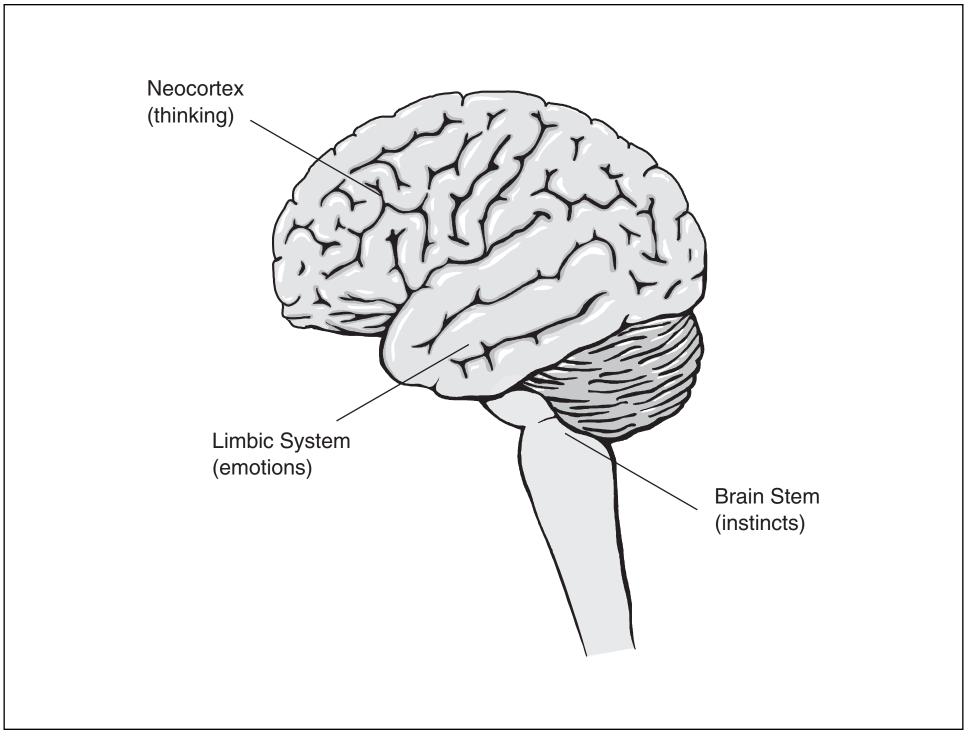



**Figure 1.4** Top to Bottom

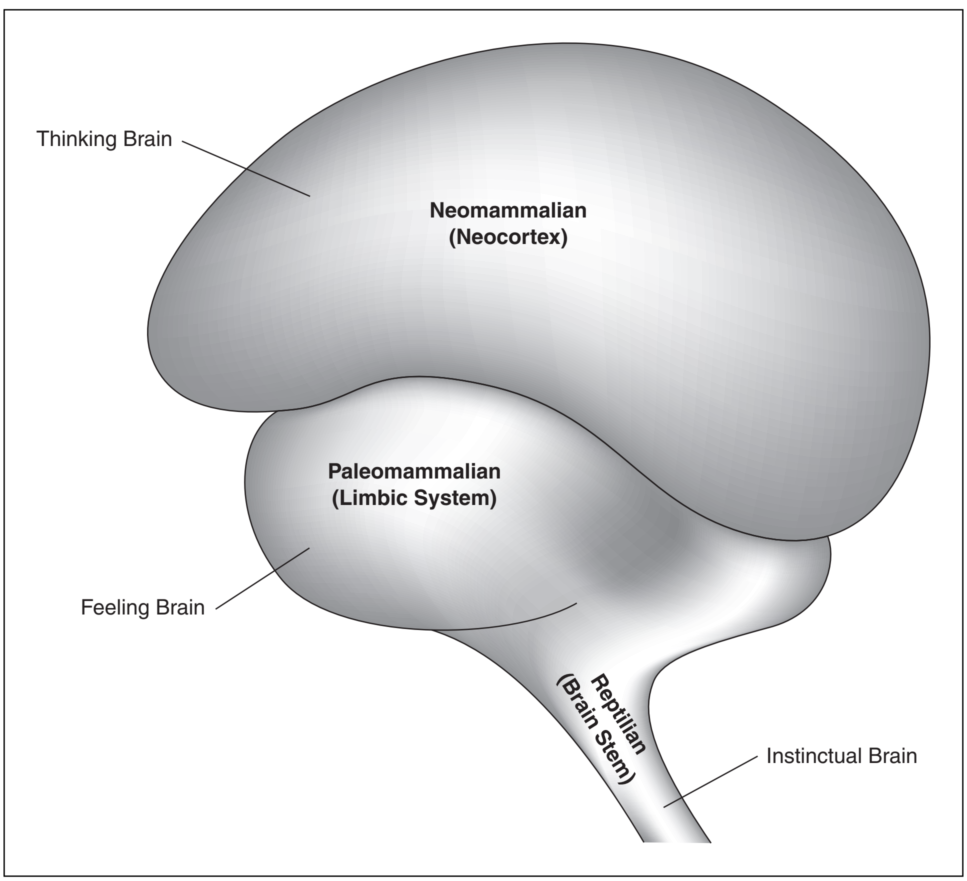



**Figure 1.5** Triune Brain Model

possibilities. It is in constant conversation with the thinking brain above it and the brain stem beneath it.

Finally, at the bottom layer, or the brain stem, is the *instinctual brain,* which governs survival mechanisms. This is the part of the brain that alerts the body to the fight-or-flight syndrome and to territorial concerns and needs for survival. It is probably the oldest part of the brain, evolving from the reptilian era as the brain adapted to its environmental needs in a Darwinian way.

### *Front-to-Back View*

According to Luria (cited in Rico, 1991), the frontal and hind lobes of the brain appear to sense temporal dimensions as well as spatial conceptual organization. This view of the brain from front to back is shown in Figure 1.6. The frontal lobe relates to the future. It is involved in planning, in making decisions, and in identifying one's sense of self. It is also the area where rehearsal takes place and where the brain allows risk taking (Sylwester, 1995, 2000a). It gives foresight (Rico, 1991) into situations. It is also the part concerned with problem solving and critical thinking. It helps make judgments, classify general categories, and estimate.

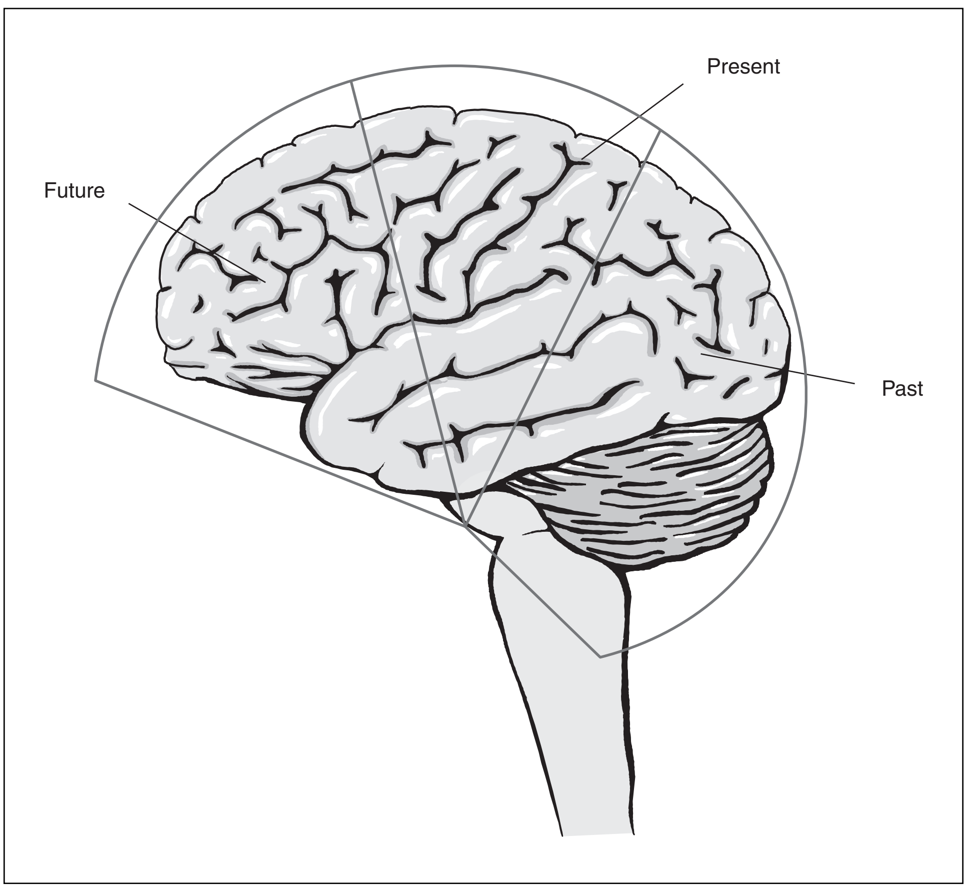



**Figure 1.6** Front to Back

The middle section is most sensitive to stimuli in the present. Because it is the center of sensory and motor input, it makes sense that it “feels” the present situations.

The hind brain, situated farthest back, focuses on the past and is where memory is processed. In this area, the temporal lobes process hearing, and the occipital lobes process vision. This part of the brain collects and retrieves information. It contains the parietal lobe, which processes touch and the integration of the senses as memories are reconstructed.

### *Left-to-Right View*

Viewed from above, the brain is divided into right and left hemispheres along a line running from the nose directly back (see Figure 1.7). The two sides are connected by the corpus callosum, which comprises a dense band of more than 200 million axons and acts as a bridge or pathway that interconnects the intricate hemispheric system.

Although lateralization (differentiation of tasks) does occur, the hemispheres are in constant communication with each other through the synchronization of the corpus callosum. Yet a closer look at the hemispheres reveals just how complex the tailoring of tasks for each side really is. Numerous researchers have documented this lateralization in terms of different ways of

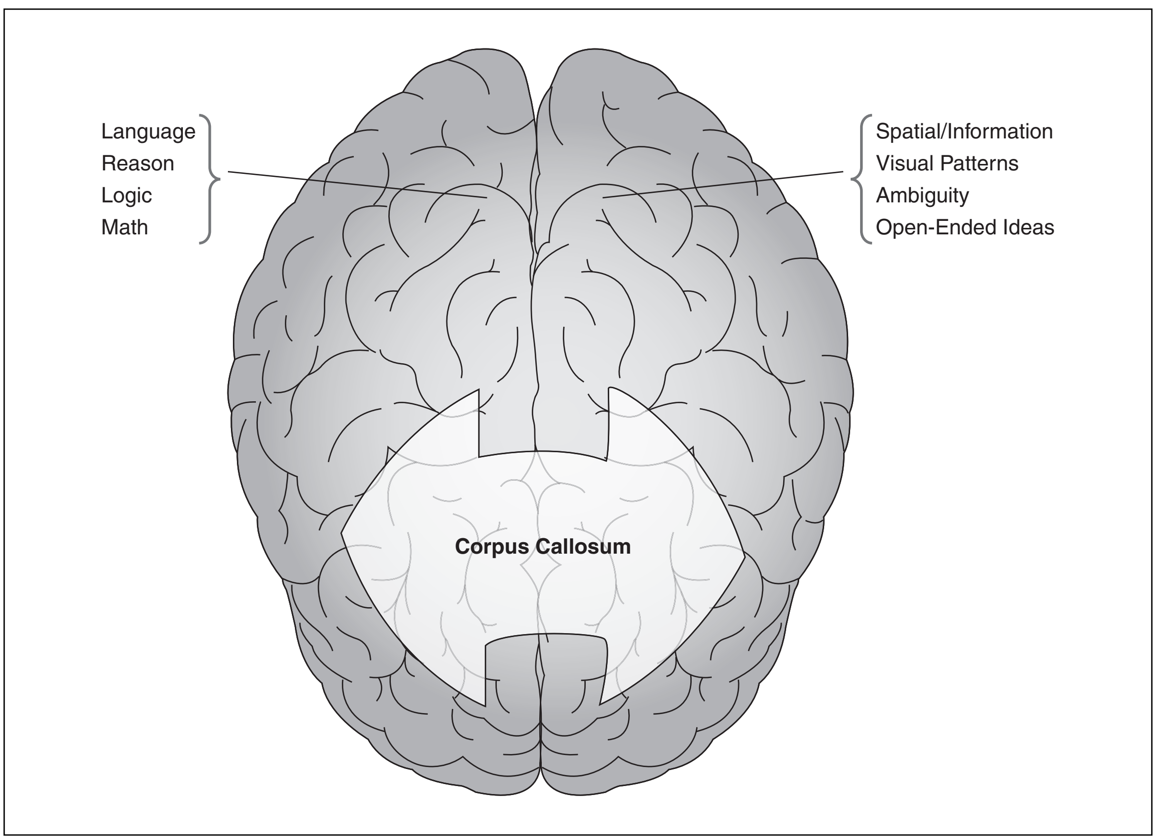



**Figure 1.7** Left and Right Hemispheres

processing related information, helping the brain combine all the information to produce a more complete mental experience. For example, the left side of the brain is thought to process language-related ideas, reasoned judgments, and logical sequencing (Hart, 2002); provide literal interpretations (Barrett, 1992); give structure and order to thoughts (Jensen, 1996a); bring critical analysis to an idea (Sylwester, 1995); split and classify ideas (Rico, 1991); and deal with numbers and the calculations of arithmetic (Sousa, 1995). While this is generally true in most right-handed people, it is true for fewer left-handed people. In fact, some people have mirror brains, where everything is reversed, and some have quite mixed-up brains.

In contrast, the right side of the brain seems to process spatial information and visual patterns (Hart, 2002), scan images, utilize intuition, and take in data simultaneously (Barrett, 1992). In addition, the right hemisphere deals with spontaneous, random, and open-ended ideas (Jensen, 1996a) as well as novel situations, paradox, and ambiguity (Rico, 1991). It relates information; reads maps, graphs, and cartoons (Sylwester, 1995); and is able to go with the flow (Jensen, 1996c).

While hemisphericity in brain research made an early debut (Sperry, 1968), current thinking is cautious to apply the left/right processing concept too rigorously or too exclusively. Tempered with the overall understanding of synchronization of the two hemispheres, a more reasoned and generally accepted view of the bilateralization of brain processing is preferred. In addition, it is more acceptable to refer to left/right hemispheres than to left/right brains.

Continuing with the exterior brain, the stem is really an extension of the spinal cord, and it is about as thick as the middle finger on a person's hand (Wolfe, 2001). The swelling on the stem is called the medulla oblongata; it governs survival, sustenance, safety, and sex. It is the main controller of heartbeat, breathing, and other instinctual reflexes such as snoring, coughing, sneezing, and even digesting. It regulates instincts, including the reflexive activities of fight or flight. As one well-known writer on brain research says, this is the brain that automatically decides and responds to the questions: Do I eat it? Fight it? Run away from it? Or mate with it? (Sylwester, 1996, 2000b).

## HOW HAS THE BRAIN EVOLVED?

### Microview: A Look at the Interior of the Human Brain

The interior brain responds through its emotional system to all sensory input. It is located in the middle brain and includes the cerebellum. This midbrain surrounds the brain stem like a half-shell or half-donut and controls the sensory input of taste and smell, memory storage, motor muscles, and movement. It controls the ability to automate the skills of riding a bike, knitting, or keyboarding. The limbic system is believed to contain the thalamus (senses), hypothalamus (emotions, body temperature, hunger, thirst, and sex drive), pituitary gland (hormones for energy), pinal gland (rate of body growth), amygdala (trigger for anger), and hippocampus (new and short-term memories). In addition, the reticular activating system (RAS; Stevens & Goldberg, 2001) acts as a master switch that alerts the brain to incoming information and to the urgency or lack of urgency in the message.

The limbic area is often referred to as the sentry at the gate—the sentry of emotions at the gate of the intellect. Emotions are seen as the gateway to the thinking mind. If the emotional guard is up, little cognitive reasoning is likely to occur. Emotions rule over reason. In fact, emotions can highjack cognitive functioning, and thinking is often blurred when emotions are high. This is illustrated in a situation in which a person is so angry and emotionally upset that he or she cannot remember a well-known phone number.

This part of the brain regulates feelings of happiness, joy, sorrow, sadness, grief, jealousy, greed, and hate. It responds emotionally to stimuli and, in states of great threat, is the default system that activates first. MacLean's (1969) early theory suggests that the limbic system is the center of emotions, and Hart (2002) presents a concept of downshifting to this emotional brain in the face of threat. Yet more current theory suggests that the emotional brain alerts the body and threat is realized subconsciously in the emotional state before it is understood in the conscious rational state. In essence, the visceral reaction puts the entire body on alert.

The neocortex covering the mid brain is considered the thinking brain. It is located in the cerebrum and considered the center of academic thought and cognitive learning. It forms the top layer of the brain and is referred to as the forebrain, upper brain, or new brain. The neocortex actually comprises 85 percent of the total brain. The cerebrum, which is as thick as a tongue depressor, is full of convolutions. Known as the thinking cap, this part of the brain handles the cognitive functions of the brain and the mind. It predicts, classifies, judges, infers, reasons, puzzles, wonders, creates, reflects, and makes sense of things. This is the part of the brain that sets humans apart from other species of animals.

## Brain Imaging: How We Know What We Know

Before getting into an in-depth discussion about the interior brain and describing how the brain actually functions, it seems appropriate to talk a bit about how researchers know what they know about the workings of the brain and what has caused this avalanche of ideas.

The major breakthrough in neurobiological research is attributed to advanced brain imaging techniques. A quick reference to these various methods reveals a concentration on three elements of brain function and neural organization: the chemical composition of cells and neurotransmitters (CAT, MRI), the electrical transmission of information along neural pathways (EEG, SQUID, BEAM), and the distribution of blood during brain activity (PET). This array of acronyms constitutes the brain imaging techniques (see Figure 1.8). Together, these techniques confirm earlier theories and revelations about how the brain functions and where particular functions occur. The explosion of information about the brain is unprecedented.

CAT: Computerized Axial Tomography

The CAT scan produces anatomical views of the brain that show three-dimensional graphical images of the density of tissue, such as bone and tumors. Multiple X-ray images can show depth of field and cross-sectional views on a computer monitor (Parker, 1995; Sylwester, 1995; Wolfe, 2001).

MRI: Magnetic Resonance Imaging

Unlike the CAT scan, the MRI focuses on soft tissue and provides a reverse image by responding to chemical differences in composition. New MRI techniques work so fast that researchers can monitor brain activity while a cognitive activity is happening (Barrett, 1992; Sylwester, 1995; Wolfe, 2001).

EEG: Electroencephalogram

Used for over 50 years, the EEG process reports patterns in electrical transmissions within an active brain. These patterns are recorded as a squiggly line graph on a roll of paper. Obtaining accurate readings and interpretations and translating a score is often difficult (Davis, 1997; Herrmann, 1995; Parker, 1995; Solso, 1997; Sylwester, 1995; Wolfe, 2001).

SQUID: Superconductivity Quantum Interference Device

The SQUID technique picks up small magnetic fields caused by the electrical current of firing neurons to pinpoint the exact source of brain activity. This identifies a more exact source of electrical activity (Barrett, 1992; Sylwester, 1995; Wolfe, 2001).

BEAM: Brain Electrical Activity Mapping

The BEAM machine records electrical activity in more precisely defined areas and uses color to represent positive and negative locations in the cerebral cortex (Sylwester, 1995; Wolfe, 2001).

PET: Positron Emission Tomography

The PET uses radioactive glucose to monitor blood flow through the brain as various areas are activated. This reveals information about how and where an experience is processed in the brain (Barrett, 1992; Sylwester, 1995; Wolfe, 2001).

**Figure 1.8** Brain Imaging Techniques: A Glossary of Terms

## HOW THE BRAIN WORKS

To fully understand how the brain works, it seems best to begin by identifying the parts of the brain cell: neuron, axon, dendrite, synapse, neurotransmitter, electrical impulse, chemical signal, glial cell, myelin, and neural network or pathway (see Figure 1.9). The brain is mostly composed of microscopic nerve cells called neurons, sometimes referred to as gray matter (Wolfe, 2001). Sylwester (1995, 2000a) describes the human brain as being composed of neurons and glial cells. *Glia* means glue, and glial cells are indeed an important part of the brain's architecture. They form part of a blood barrier to protect the brain from dangerous molecules that travel in the bloodstream. Glial cells also form a layer of insulation (myelin) around nerve fibers, which strengthens and increases the neural messages.

The neuron can be compared to a drawing of a human arm, hand, and fingers, as shown in Figure 1.10. The cell body is like the hand, the axon like the arm (acting as a conductor that sends the impulse to the next cell), and the

NEURON: nerve cell that comprises gray and white matter in the brain

GLIAL CELL: cell that splits and duplicates to act as glue to strengthen brain cells

MYELIN: coating on the axon that serves as an insulator and speeds up transmission for outgoing messages

AXON: long fiber that sends electrical impulses and releases neurotransmitters

DENDRITE: short branching that receives the chemical transmitters

SYNAPSE: small gap between neurons through which neurotransmitters move

NEUROTRANSMITTER: chemical molecule that travels within and between brain cells

ELECTRICAL IMPULSE: the nerve message received and sent out by the neurons

CHEMICAL SIGNAL: a message carried from neuron to neuron; chemical molecules called neurotransmitters travel across synapses

NEURAL NETWORK: a set of connected neurons that form a strengthened path that speeds the passage of the neurotransmitters

**Figure 1.9** The Brain Cell: A Glossary of Terms

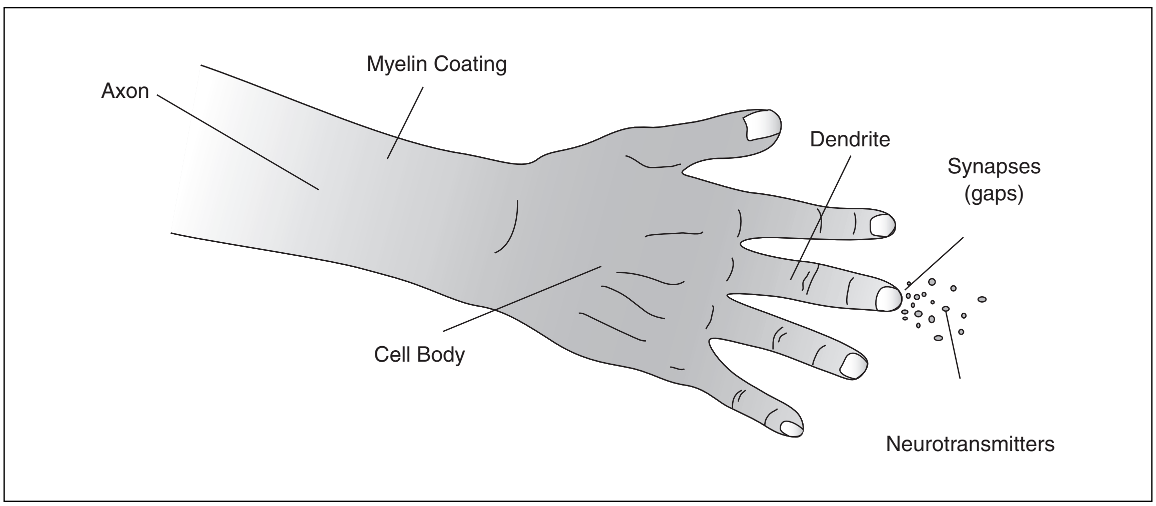



**Figure 1.10** Physical Model of a Neuron

fingers form the equivalent of the dendrites, the receptors of the impulse (Sylwester 1995, 2000b).

When the neuron receives a message from the senses, muscles, or other neurons, it is received as an electrical impulse. This impulse is processed inside the cell and then sent out to other neurons by way of the axons (Wolfe, 1996). Traveling at speeds of 100 miles per hour, the impulse travels on the outside of the axon. When the electrical impulse reaches the end of the axon, near the dendrite branches, chemical neurotransmitters are released into the synapse

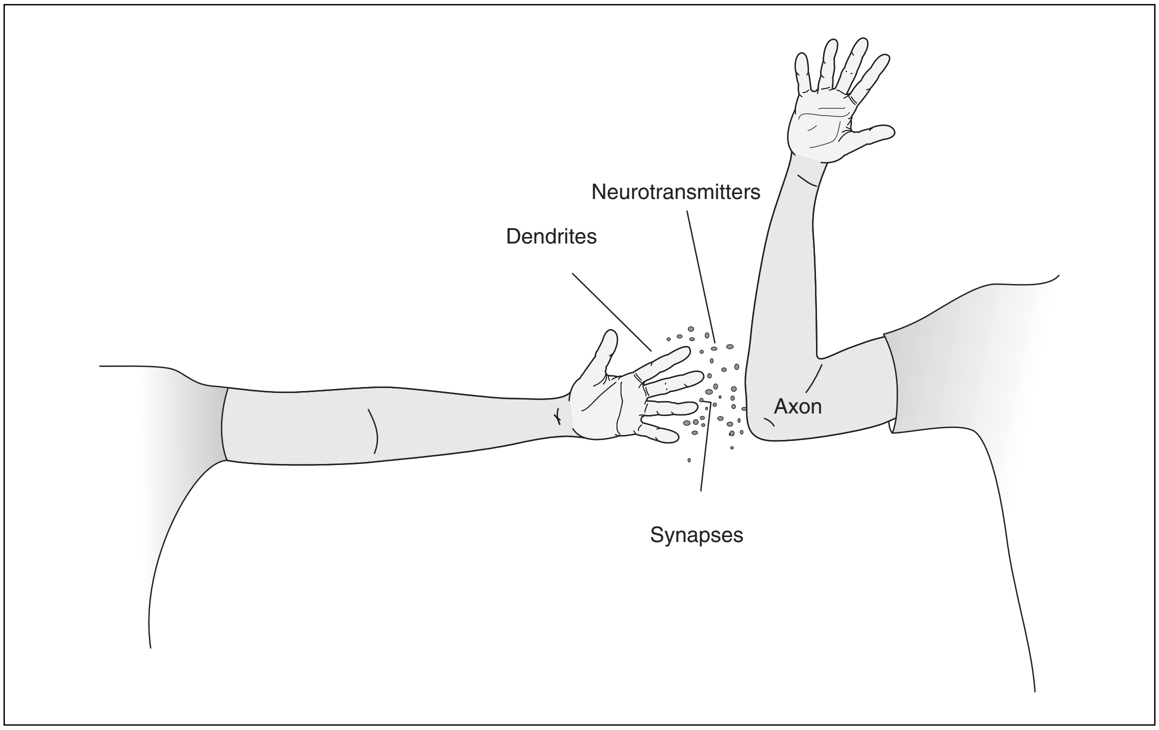



**Figure 1.11** Synaptic Connection

and are received by the dendrite (Sylwester 1995, 2000b). These synapses allow neurons to communicate with each other (see Figure 1.11). Thus, the reaction along the axon is electrical, while the reaction between the cells is chemical (Parker 1995). This process results in electrochemical interactions.

The axon sends the electrical impulse to the dendrites through chemical messengers called neurotransmitters. The dendrites receive the messengers in little coves, or gaps, called synapses. The chemical message enters the neighboring brain cell and is translated into another electrical impulse within the cell. Brain cells talk to each other through the chemical messengers at the synaptic connections (Sylwester, 2000a; Wolfe, 2001).

A more scientific look at the synaptic connection highlights the strength of the dendrites (see Figure 1.12).

A still closer look at the synaptic connection reveals the intricate path of the neurotransmitters (see Figure 1.13).

## Neurotransmitters

Neurotransmitters are the chemical messengers that communicate between neurons at the synapse, or the narrow gap between the axon and the dendrite. They are released as the electrical neural impulse is passed from one neuron to another (Sylwester, 2000b; Wolfe, 2001). Scientists have identified more than 50 neurotransmitters, but for the sake of this introductory chapter on the brain, only a few are defined in this text. They are grouped into three categories: amino acids, monoamines, and peptides (see Figure 1.14).

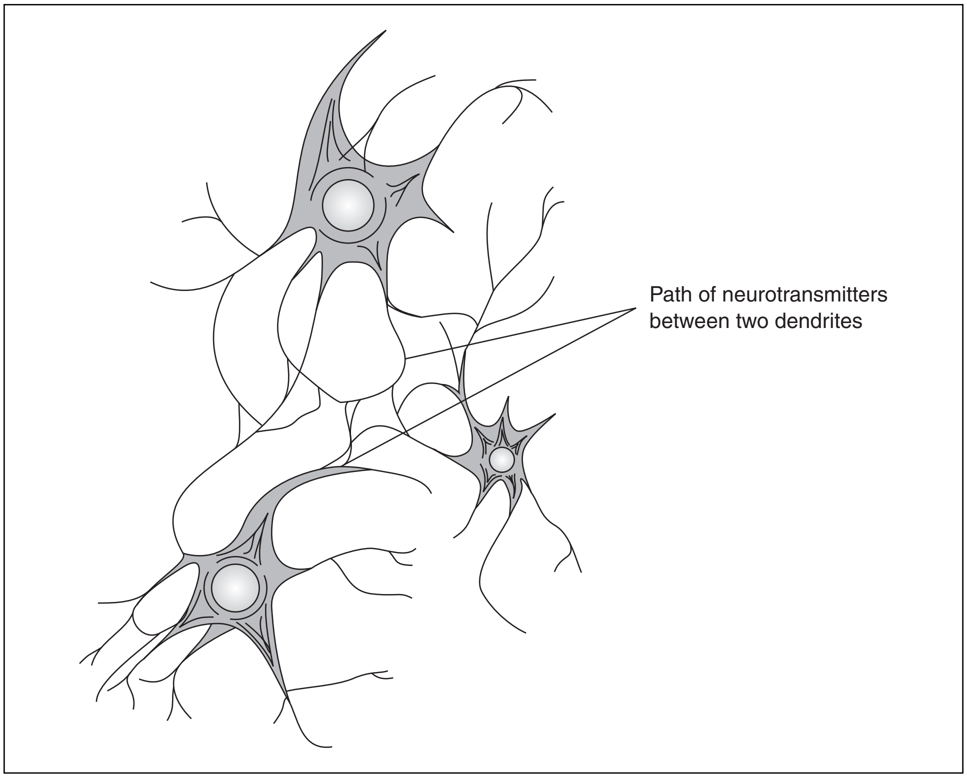



**Figure 1.12** Neuron Communication

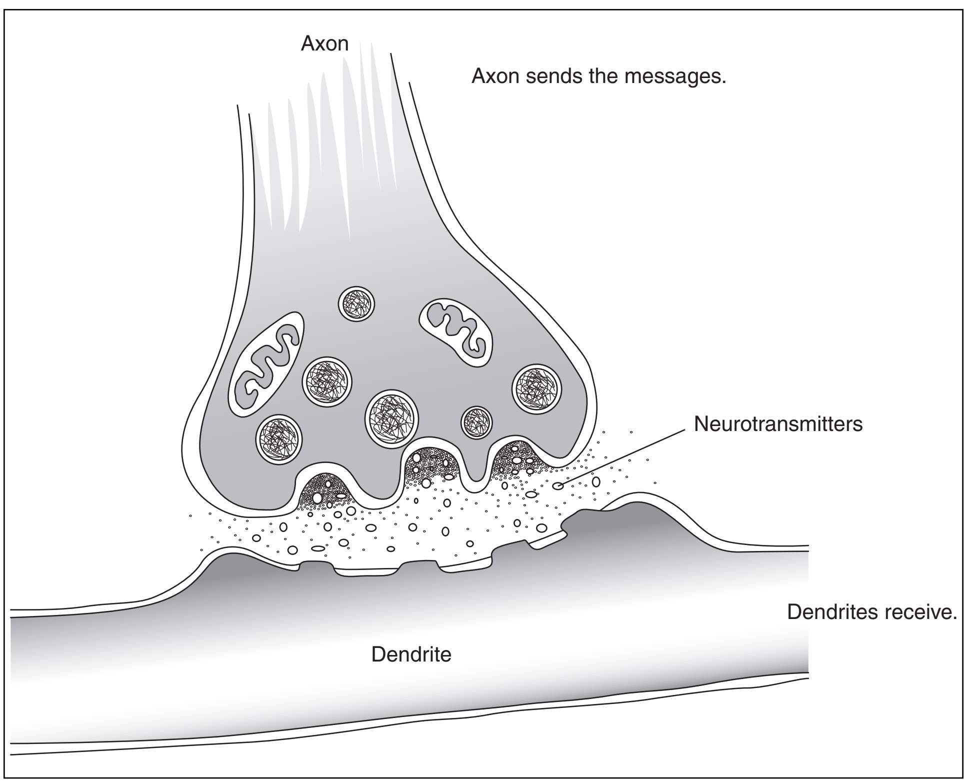



**Figure 1.13** Synapse

Amino Acids (Principal)

SIMPLE GLUTAMATE: excitatory neurotransmitter (vision, learning, and memory)

GABA OR GLYCINE: inhibitory neurotransmitter (reduces anxiety and relaxes muscles)

Monoamines (Modified)

DOPAMINE: regulates complex emotional behaviors and conscious movements

SEROTONIN: regulates body temperature, sensory perception, and the onset of sleep

NOREPINEPHRINE: regulates arousal, activation, fight-or-flight response

Peptides (Complex)

ENDORPHIN: reduces pain, enhances euphoria

VASOPRESSIN: water retention, blood pressure, memory

**Figure 1.14** Neurotransmitters: A Sample Glossary of Terms

Amino acids are the principal neurotransmitters. They carry excitatory or inhibitory messages. Monoamines determine whether the message sent is excitatory or inhibitory. Peptides, or classical neurotransmitters, affect complex behavior patterns such as pain and pleasure.

In this way, billions of nerve cells connect to each other in billions of combinations, forming trillions of pathways for nerve signals to follow. What results is referred to as dendritic growth, and the dendrites continue to grow and interconnect throughout a lifetime. These brain connections, or neural pathways, are wired and rewired constantly, continually, and incessantly as stimuli are processed by the brain (see Figure 1.15). The possible combinations are mind-boggling as the permutations expand (Sylwester, 2000a; Wolfe, 2001).

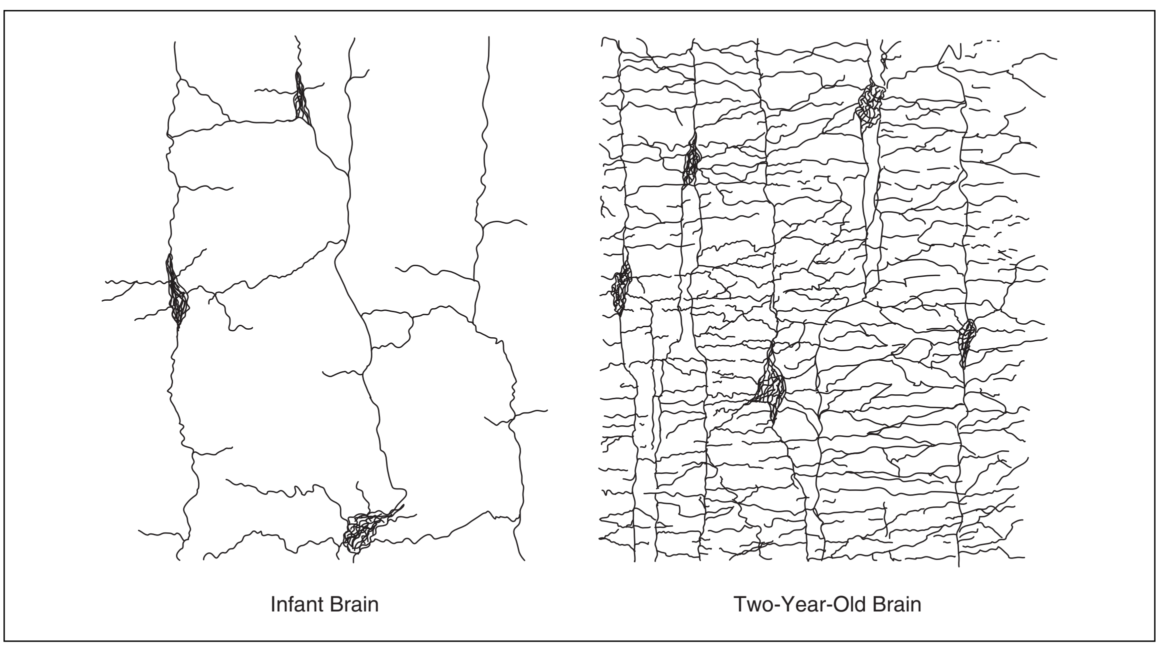



**Figure 1.15** Diagram of Growing Dendrites

Documented by Potter and Orfali (1993), an additional commentary on dendritic growth is the age-old axiom: Use it or lose it! (Wolfe, 2001). Just as stimulation fosters the growth of dendrites, the lack of stimuli causes the existing connection to weaken and even to disappear. While pruning (the natural weeding of old, unused dendritic connections, or neural pathways) is a natural process in growing dendrites, the concept of losing brain capacity refers to dramatic situations in which there is almost a total lack of stimulation for brain growth (Wolfe, 1996).

## DIFFERENCES BETWEEN MALES AND FEMALES

Gender difference in brain physiology and functioning is an important concept to understand. It appears in literature about the brain, and it helps explain how the sexes process information differently. Gender differences occur in the area of emotions and in spatial navigation. Certain gender differences in brain functioning have been documented in terms of the location in which the processing occurs (Howard, 2006); for example, “the male’s separation of language specialization in the left hemisphere and emotional specialization in the right helps to explain his traditional ineptness at talking about feelings” (p. 268). These and other differences, such as better visual perception and differentiation in males and greater verbal acuity in females, seem to appear most often after puberty.

There are differences in brain chemistry, length of nerve cells, density of nerve strands, and how information is processed in males and females. In fact, hormonal levels are the greatest indicators of gender-related differences in thinking and problem solving. In males, testosterone levels correlate with aggression, competition, self-assertion, self-confidence, and self-reliance. In females, when progesterone and estrogen levels are high, math and spatial abilities tend to be lower.

In terms of physiology and processing of information, Figure 1.16 depicts the most noticeable differences between males and females.

| *Males* | *Females* |
|---|---|
| More cortical areas devoted to spatial-mechanical | More cortical areas devoted to verbal-emotive—use more words than males |
| Prefrontal lobe less active at earlier age—decision making more impulsive | Prefrontal lobe more active—can make less impulsive decisions, better literacy |
| Natural rest state many times a day—not as well suited to school day | Brain functioning stays active—more likely to retain information |
| Natural aggression—lateralize and compartmentalize in hemisphere | More cross talk between hemispheres—better multitasking |
| Visual system, type M ganglion cells—detect movement | Visual system, P ganglion cells—sensitive to color |

**Figure 1.16** More Than 100 Structural Differences Between Male and Female Brains

SOURCE: King & Gurian, 2006.

In brief, males and females process sensory input differently, using different parts of the brain. Although the brain is wired in the womb, the differences seem to be more noticeable after puberty. Gender differences are innately interesting, and the more that is known, the more educators are able to tailor learning to the preferences of both genders.