How the Brain Learns

Sixth Edition

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David A. Sousa

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Preface

Teaching is one of the most challenging professions. But it is also one of the most rewarding because teachers can make such a positive difference in their students' lives. My hope is that publishing a sixth edition of this book will lessen the stress of the challenges and enhance the rewards that come with successful teaching and learning. This revision also recognizes that research in cognitive neuroscience continues to provide exciting new insights into how the brain develops and learns. Because teachers are essentially "brain changers," they realize that the more they know about how the brain learns, the more likely they are to be effective at helping their students succeed.

Some good news is that the academic discipline called "educational neuroscience" or "mind, brain, and education science" is now firmly established. This field of inquiry explores how research findings from neuroscience, education, and psychology can inform our understandings about teaching and learning and whether they have implications for educational practice. This interdisciplinary approach ensures that recommendations for teaching practices have a foundation in solid scientific research. The task remains to get these important findings to as many educators as possible.

For this sixth edition, I have made numerous changes that reflect new advances in our understanding of the learning process. Specifically, I have

- separated and expanded the previous edition's Chapter 5 into two chapters: Chapter 5 on "Brain Organization and Learning" and Chapter 6 on "Learning to Read and Learning Mathematics;"
- revised the section on Bloom's taxonomy to include Webb's Depth of Knowledge framework;
- added a section on the need for cognitive rigor;
- added an extensive section on the power of student academic teaming to enhance achievement;
- added an extensive section on the importance and benefits of student agency;
- added a section on giving adequate attention to social–emotional learning;
- added several new Practitioner's Corners;
- updated the Resources section to include more internet sites selected for their reliable information on the brain; and
- added or updated more than 175 references, most of which are primary sources for those who wish to explore the actual research studies.

This continues to be an exciting time to be in education. Granted, never has society asked so much of its schools. At the same time, however, never have we known so much about how students learn and what we can do to make that happen successfully. This book opens the door to educational neuroscience in the hope that educators will experience the joy of seeing more students reach their full potential.

—David A. Sousa

About the Author

David A. Sousa, EdD, an international consultant in educational neuroscience, has written more than 20 books for educators and parents on ways to use brain research to improve teaching and learning. He has conducted workshops for more than 200,000 educators in hundreds of school districts on brain research and science education at the Pre-K to Grade 12 and university levels. He has presented at national conventions of educational organizations and to regional and local school districts across the United States, Canada, Europe, Australia, New Zealand, and Asia.

Dr. Sousa has a bachelor of science degree in chemistry from Bridgewater (Massachusetts) State University, a master of arts degree in teaching science from Harvard University, and a doctorate from Rutgers University. His teaching experience covers all levels. He has taught high school science and has served as a K–12 director of science, a supervisor of instruction, and a district superintendent in New Jersey schools. He has been an adjunct professor of education at Seton Hall University and at Rutgers University. A past president of the National Staff Development Council (now called Learning Forward), Dr. Sousa has edited science books and published numerous articles in leading educational journals on professional development, science education, and brain research. He has received awards from professional associations, school districts, and Bridgewater State University (Distinguished Alumni Award), as well as several honorary doctorates for his commitment and contributions to research, professional development, and science education. He has been interviewed on the NBC *Today* show, on National Public Radio, and other programs about his work with schools using brain research. He makes his home in south Florida.

CHAPTER 1

Basic Brain Facts

> *With our new knowledge of the brain, we are just dimly beginning to realize that we can now understand humans, including ourselves, as never before, and that this is the greatest advance of the century, and quite possibly the most significant in all human history.*
>
> **—Leslie A. Hart**
> ***Human Brain and Human Learning***

CHAPTER HIGHLIGHTS

This chapter introduces some of the basic structures of the human brain and their functions. It explores the growth of the young brain and some of the environmental factors that influence its development into adolescence. Whether the brain of today's student is compatible with today's schools and the impact of technology are also discussed.

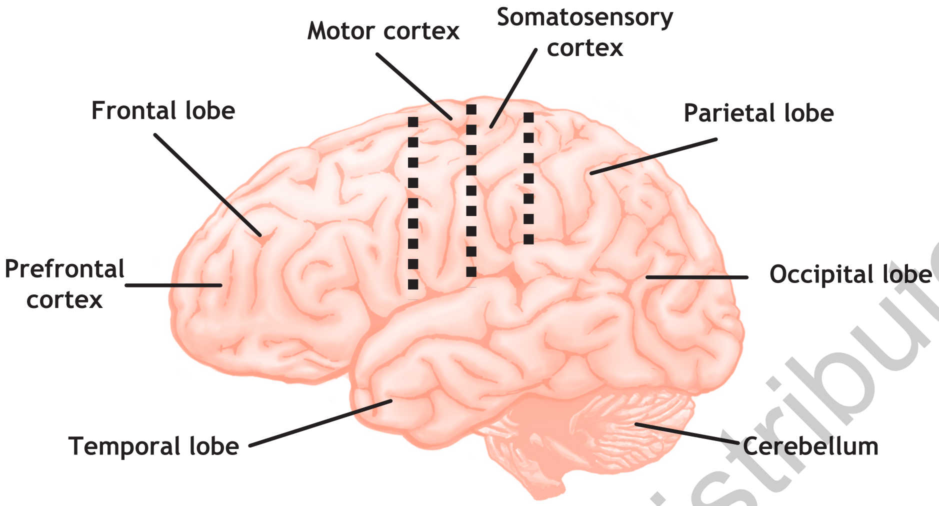
The adult human brain is a wet, fragile mass that weighs a little more than three pounds (1.4 kg.). It is about the size of a small grapefruit, is shaped like a walnut, and can fit in the palm of your hand. Cradled in the skull and surrounded by protective membranes, it is poised at the top of the spinal column. The brain works ceaselessly, even when we are asleep. Although it represents only about 2 percent of our body weight, it consumes nearly 20 percent of our calories! The more we think, the more calories we burn. Perhaps this can be a new diet fad, and we could modify Descartes' famous quotation from "I think, therefore I am" to "I think, therefore I'm thin"!

Through the centuries, surveyors of the brain have examined every cerebral feature, sprinkling the landscape with Latin and Greek names to describe what they saw. They analyzed structures and functions and sought concepts to explain their observations. These observations were often of individuals who had damage to certain areas of the brain. If the damage resulted in a specific functional deficit, then the researchers surmised that the affected area was most likely responsible for that function. For example, physicians noted that damage to the part of the brain behind the left temple often resulted in temporary loss of speech (called **aphasia**). Therefore, they inferred that this area must be related to spoken language, and indeed it is.

One early concept of brain structure divided the brain by location—forebrain, midbrain, and hindbrain. Another, proposed by Paul MacLean (1990) in the 1960s, described the triune brain according to three stages of evolution: reptilian (brain stem), paleo-mammalian (limbic area), and mammalian (frontal lobes).

For our purposes, we will take a look at major parts of the outside of the brain (see Figure 1.1). We will then look at the inside of the brain and divide it into three parts on the basis of their general functions: the brain stem, limbic system, and cerebrum (see Figure 1.2). We will also examine the structure of the brain's nerve cells, called **neurons**.

FIGURE 1.1 The Major Exterior Regions of the Brain



Video: For more information on structures of the brain, see http://www.nimh.nih.gov/brainbasics/index.html.

SOME EXTERIOR PARTS OF THE BRAIN

LOBES OF THE BRAIN

Although the minor wrinkles are unique in each brain, several major wrinkles and folds are common to all brains. These folds form a set of four lobes in each hemisphere. Each lobe tends to specialize for certain functions.

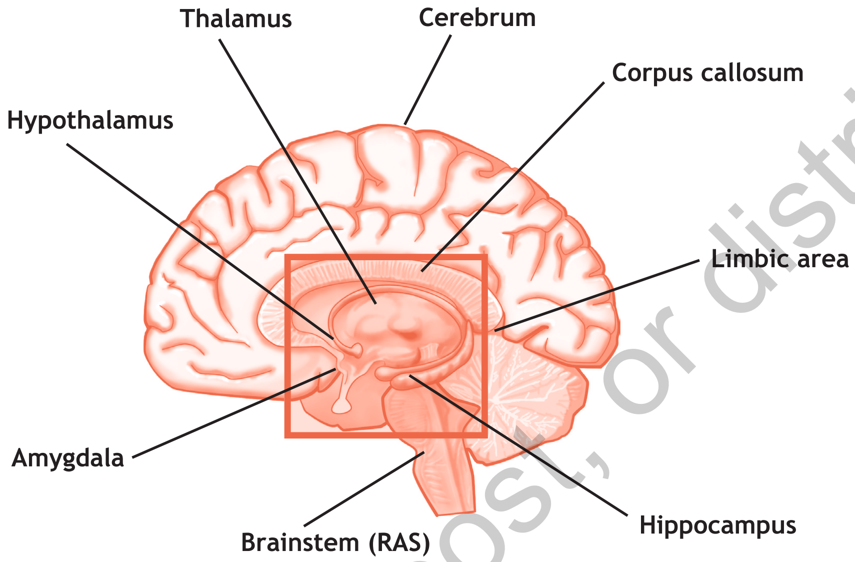
Frontal Lobes. At the front of the brain are the **frontal lobes**, and the part lying just behind the forehead is called the *prefrontal cortex.* Often called the executive control center or rational system, these lobes deal with planning and thinking. They comprise the rational and executive control center of the brain, monitoring higher-order thinking, directing problem-solving, and regulating the excesses of the emotional system. The frontal lobe also contains our self-will area—what some might call our personality. Trauma to the frontal lobe can cause dramatic—and sometimes permanent—behavior and personality changes, including loss of speech and difficulties with memory. Because most of the working memory is located here, it is the area where focus mostly occurs (Funahashi, 2017; Stemmann & Freiwald, 2019). The frontal lobe matures slowly. MRI studies of postadolescents reveal that the frontal lobe continues to mature into early adulthood. Thus, the capability of the frontal lobe to control the excesses of the emotional system is not fully operational during adolescence (Dosenbach et al., 2010; Shanmugan & Satterthwaite, 2016). This is one important reason why adolescents are more likely than adults to submit to their emotions and resort to high-risk behavior.

Temporal Lobes. Above the ears rest the *temporal lobes*, which deal with sound, music, face and object recognition, and some parts of long-term memory. They also house the speech centers, although this is usually on the left side only. Damage to the temporal lobes may affect hearing, the recognition of a familiar person's face, and the processing of sensory information.

Occipital Lobes. At the back are the paired *occipital lobes*, which are used almost exclusively for visual processing, including perceiving shapes and colors. Damage to these lobes can cause distorted vision.

Parietal Lobes. Near the top are the *parietal lobes*, which integrate sensory information from various parts of the body (e.g., hot, cold, touch, pain) and help with spatial orientation. Damage in this area may affect the ability to recognize and locate parts of your body.

FIGURE 1.2 A Cross Section of the Human Brain



MOTOR CORTEX AND SOMATOSENSORY CORTEX

Between the parietal and frontal lobes are two bands across the top of the brain from ear to ear. The band closer to the front is the **motor cortex**. This strip controls body movement and, as we will learn later, works with the cerebellum to coordinate the learning of motor skills. Just behind the motor cortex, at the beginning of the parietal lobe, is the *somatosensory cortex*, which processes touch signals received from various parts of the body.

Because the rational system matures slowly in adolescents, they are more likely to submit to their emotions.

SOME INTERIOR PARTS OF THE BRAIN

BRAIN STEM

The **brain stem** is the oldest and deepest area of the brain. It is often referred to as the reptilian brain because it resembles the entire brain of a reptile. Of the 12 body nerves that go to the brain, 11 of them end in the brain stem (the olfactory nerve—for smell—goes directly to the limbic system, an evolutionary artifact). Here is where vital body functions, such as heartbeat, respiration, body temperature, and digestion, are monitored and controlled. The brain stem also houses the **reticular activating system** (RAS), responsible for the brain's alertness and about which more will be explained in the next chapter.

THE LIMBIC SYSTEM

Nestled above the brain stem and below the cerebrum lies a collection of structures commonly referred to as the *limbic system* and sometimes called the *old mammalian brain*. Many researchers now caution that viewing the limbic system as a separate functional entity is outdated because all its components interact with many other areas of the brain.

Most of the structures in the limbic system are duplicated in each hemisphere of the brain. These structures carry out a number of different functions, including generating emotions and processing emotional memories. Its placement between the cerebrum and the brain stem permits the interplay of emotion and reason.

Four parts of the limbic system are important to learning and memory:

The Thalamus. All incoming sensory information (except smell) goes first to the **thalamus** (Greek for "inner chamber"). From here, it is directed to other parts of the brain for additional processing. The cerebrum and the cerebellum also send signals to the thalamus, thus involving it in many cognitive activities, including memory.

The Hypothalamus. Nestled just below the thalamus is the **hypothalamus**. While the thalamus monitors information coming in from the outside, the hypothalamus monitors the internal systems to maintain the normal state of the body (called *homeostasis*). By controlling the release of a variety of hormones, it moderates numerous body functions, including sleep, body temperature, food intake, and liquid intake. If body systems slip out of balance, it is difficult for the individual to concentrate on cognitive processing of curriculum material.

The Hippocampus. Located near the base of the limbic area is the **hippocampus** (the Greek word for "sea horse" because of its shape). It plays a major role in consolidating learning and in converting information from working memory via electrical signals to the **long-term storage** regions, a process that may take days to months. It constantly checks information relayed to working memory and compares it to stored experiences. This process is essential for the creation of meaning.

Its role was first revealed by patients whose hippocampus was damaged or removed because of disease. These patients could remember everything that happened before the operation, but not what happened afterward. If they were introduced to you today, you would be a stranger to them tomorrow. Because they can remember information for only a few minutes, they can read the same article repeatedly and believe on each occasion that it is the first time they have read it. Brain scans and case studies continue to confirm the role of the hippocampus in permanent memory storage (e.g., Biderman et al., 2020; Huijgen & Samson, 2015; Postle, 2016). Alzheimer's disease progressively destroys neurons in the hippocampus, resulting in memory loss.

Studies of brain-damaged patients have revealed that the hippocampus plays an important role in the recall of facts, objects, and places. One revelation in recent years is that the hippocampus seems to possess the capability to produce new neurons—a process called **neurogenesis**—into adulthood (Balu & Lucki, 2009). Furthermore, there is research evidence that neurogenesis may have an impact on learning and memory (Deng et al., 2010; Terranova et al., 2019). However, measuring neurogenesis in humans is very difficult. Consequently, researchers do not yet fully agree on the role neurogenesis plays in brain growth and development.

The Amygdala. Attached to the end of the hippocampus is the **amygdala** (Greek for "almond" because of its shape and size). This structure plays an important role in emotions, especially fear. It regulates the individual's interactions with the environment that can affect survival, such as whether to attack, escape, mate, or eat.

Because of its proximity to the hippocampus and its activity on brain scans, researchers believe that the amygdala encodes an emotional message, if one is present, whenever a memory is tagged for long-term storage. It is uncertain whether the emotional memories themselves are actually stored in the amygdala. Research evidence is leaning toward the possibility that the emotional component of a memory is stored in the amygdala while other cognitive components (names, dates, etc.) are stored elsewhere (Hermans et al., 2014). The emotional component is recalled whenever the memory is recalled. This explains why people recalling a strong emotional memory will often experience those emotions again. Interactions between the amygdala and the hippocampus ensure that we remember for a long time those events that are important and emotional.

Teachers, of course, hope that their students will permanently remember what was taught. Therefore, it is intriguing to realize that the two structures in the brain mainly responsible for long-term remembering are located in the *emotional* area of the brain. Understanding the significant connection between emotions and cognitive learning and memory will be discussed in later chapters.

Test Question No. 1: The structures responsible for deciding what gets stored in long-term memory are located in the brain's rational system. True or false?

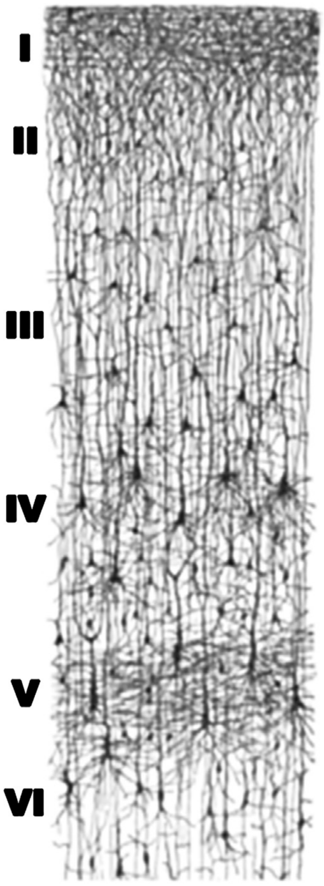
Answer: False. These structures are located in the emotional (limbic) system.

CEREBRUM

A soft, jellylike mass, the **cerebrum** is the largest area, representing nearly 80 percent of the brain by weight. Its surface is pale gray, wrinkled, and marked by deep furrows called **fissures** and shallow ones called *sulci* (singular: **sulcus**). Raised folds are called *gyri* (singular: **gyrus**). One large sulcus runs from front to back and divides the cerebrum into two halves, called the *cerebral hemispheres*. For some still-unexplained reason, the nerves from the left side of the body cross over to the right hemisphere, and those from the right side of the body cross to the left hemisphere. The two hemispheres are connected by a thick cable of more than 200 million nerve fibers called the **corpus callosum** (Latin for "large body"). The hemispheres use this bridge to communicate with each other and coordinate activities.

The hemispheres are covered by a thin but tough laminated **cortex** (meaning "tree bark"), which is rich in cells, about one-tenth of an inch thick and, because of its folds, has a surface area of about two square feet. That is about the size of a large dinner napkin. The cortex is composed of six layers of cells meshed in about 10,000 miles of connecting fibers per cubic inch! Here is where most of the action takes place. Thinking, memory, speech, and muscular movement are controlled by areas in the cerebrum. The cortex is often referred to as the brain's gray matter.

FIGURE 1.3 This drawing shows a cross section of the human cerebral cortex with the six layers labeled I through VI. Below layer VI is the white matter.



These cells were first discovered in the late 1800s by Santiago Ramón y Cajal (1989), a Spanish pathologist and neuroscientist. Figure 1.3 is a drawing from his notebook showing the neurons in the thin cortex forming columns whose branches extend through six cortical layers into a dense web below known as the white matter. Here, neurons connect with each other to form vast arrays of neural networks that carry out specific functions. The drawing is surprisingly accurate.

CEREBELLUM

The **cerebellum** (Latin for "little brain") is a two-hemisphere structure located just below the rear part of the cerebrum, right behind the brain stem. Representing about 11 percent of the brain's weight, it is a deeply folded and highly organized structure containing more neurons than all of the rest of the brain put together. The surface area of the entire cerebellum is about the same as that of one of the cerebral hemispheres.

This area coordinates movement. Because the cerebellum monitors impulses from nerve endings in the muscles, it is important in the performance and timing of complex motor tasks. It modifies and coordinates commands to swing a golf club, smooth a dancer's footsteps, and allow a hand to bring a cup to the lips without spilling its contents. The cerebellum may also store the memory of automated movements, such as touch-typing and tying a shoelace. Through such automation, performance can be improved as the sequences of movements can be made with greater speed, greater accuracy, and less neural effort. The cerebellum also is known to be involved in the mental rehearsal of motor tasks, which also can improve performance and make it more skilled. A person whose cerebellum is damaged slows down and simplifies movement and would have difficulty with finely tuned motion, such as catching a ball or completing a handshake.

The role of the cerebellum has often been underestimated. Research studies suggest that it also acts as a support structure in cognitive processing by coordinating and fine-tuning our thoughts, emotions, senses (especially touch), and memories (e.g., Hertrich et al., 2016; Marvel & Desmond, 2016). Because the cerebellum is connected also to regions of the brain that perform mental and sensory tasks, it can perform these skills automatically, without conscious attention to detail. This allows the conscious part of the brain the freedom to attend to other mental activities, thus enlarging its cognitive scope. Such enlargement of human capabilities is attributable in no small part to the cerebellum and its contribution to the automation of numerous mental activities.

The cerebellum continues to offer up surprises as to its functions. Recent research suggests that the cerebellum plays an important role in social and reward-related behavior (Carta et al., 2019). This discovery may explain why previous brain imaging showed connections between the cerebellum and other brain areas associated with addictive behaviors.

BRAIN CELLS

The brain is composed of about a trillion cells of at least two known types: nerve cells and **glial cells**. The nerve cells are called *neurons* and represent about a tenth of the total—roughly 100 billion. Most of the cells are *glial* (Greek for "glue") cells that hold the neurons together and act as filters to keep harmful substances out of the neurons. Star-shaped glial cells, called **astrocytes**, have a role in regulating the rate of neuron signaling. By attaching themselves to blood vessels, astrocytes also serve to form the blood–brain barrier, which plays an important role in protecting brain cells from blood-borne substances that could disrupt cellular activity.

The neurons are the functioning core for the brain and the entire nervous system. Neurons come in different sizes, but the body of each brain neuron is about one-hundredth of the size of the period at the end of this sentence. Unlike other cells, the neuron (see Figure 1.4) has tens of thousands of branches emerging from its core, called **dendrites** (from the Greek word for "tree"). The dendrites receive electrical impulses from other neurons and transmit them along a long fiber, called the **axon** (Greek for "axis"). There is normally only one axon per neuron. A layer called the *myelin sheath* surrounds each axon. The sheath insulates the axon from the other cells, prevents the electric charge from leaking into the environment, and thereby increases the speed of impulse transmission. This impulse travels along the neurons through an electrochemical process and can move through the entire length of a six-foot (183 centimeters) adult in two-tenths of a second. A neuron can transmit between 250 and 2,500 impulses per second.

Neurons have no direct contact with each other. Between each dendrite and axon is a small gap of about a millionth of an inch (25 millionths of a millimeter) called a **synapse** (from the Greek, meaning "to join together"). A typical neuron collects signals from its neighbors through the dendrites, which are covered at the synapse with thousands of tiny bumps called *spines*. The neuron sends out spikes of electrical activity (impulses) through the axon to its end (called the *presynaptic terminal*) at the synapse. This activity releases chemicals stored in sacs (called *synaptic vesicles*) at the end of the axon (see Figure 1.5). These chemicals (called **neurotransmitters**) move across the synaptic gap and either excite or inhibit the end (*postsynaptic terminal*) of the neighboring neuron. The impulse then moves along this neuron's axon to other neurons, and so on. Learning occurs by changing the synapses so that the influence of one neuron on another also changes.

About 100 different neurotransmitters have been discovered so far, but only about 10 of them do most of the work. The following are some of the common neurotransmitters:

Acetylcholine (affects learning, movement, memory, and REM sleep)

Epinephrine (affects metabolism of glucose, release of energy during exercise)

Serotonin (affects sleep, impulsivity, mood, appetite, and aggression)

Glutamate (most predominate one that affects learning and emotion)

Endorphins (relief from pain, feelings of well-being and pleasure)

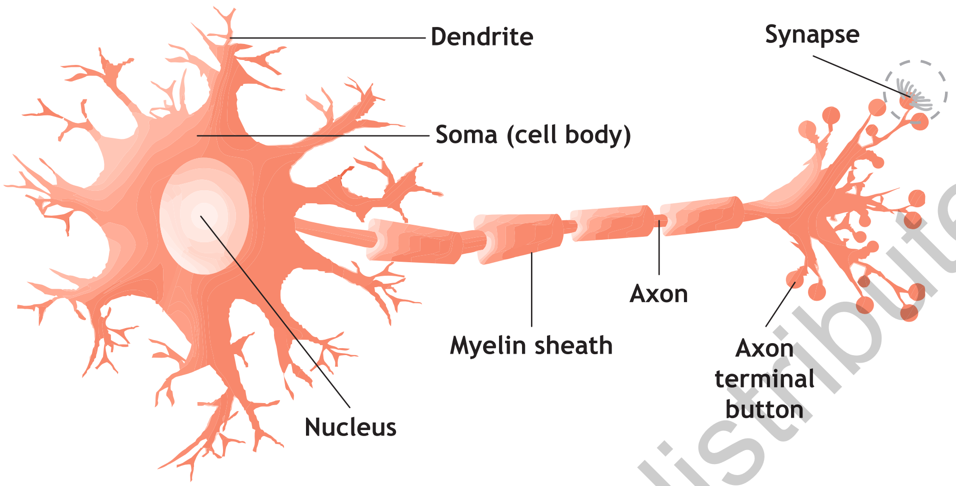
Dopamine (affects movement, attention, learning, pleasure, and reinforcement)

Essentially, messages move *along* the neuron electrically but *between* neurons chemically.

A direct connection seems to exist between the physical world of the brain and the work of the brain's owner. Studies of neurons in people of different occupations (e.g., professional musicians) show that the more complex the skills demanded of the occupation, the greater the number of dendrites on the neurons. This increase in dendrites allows for more connections between neurons, resulting in more sites in which to store learnings.

We already mentioned that there are about 100 billion neurons in the adult human brain—about 14 times as many neurons as people on this planet and roughly the number of stars in the Milky Way. Each neuron can have up to 10,000 dendrite branches. This means that it is possible to have up to one quadrillion (that is a 1 followed by 15 zeros) synaptic connections in one brain. This inconceivably large number allows the brain to process the data coming continuously from the senses; to store decades of memories, faces, and places; to learn languages; and to combine information in a way that no other individual on this planet has ever thought of before. This is a remarkable achievement for just three pounds of soft tissue!

FIGURE 1.4 **Neurons transmit signals along an axon and across the synapse (in dashed circle) to the dendrites of a neighboring cell. The myelin sheath protects the axon and increases the speed of transmission.**



Believe it or not, the number of potential synaptic connections in just one human brain is about 1,000,000,000,000,000.

Conventional wisdom has held that neurons are the only body cells that never regenerate. However, we noted earlier that researchers have discovered that the adult human brain appears to generate neurons in at least one site—the hippocampus. This discovery raises the question of whether neurons regenerate in other parts of the brain and, if so, whether it is possible to stimulate them to repair and heal damaged brains, especially for the growing number of people with Alzheimer's disease (Babcock et al., 2021). Research into Alzheimer's disease is exploring ways to stop the deadly mechanisms that trigger the destruction of neurons.

Video: To see an animation of neurotransmitters crossing the synaptic gap, go to https://www.youtube.com/watch?v=ecGEcj1tBBI.

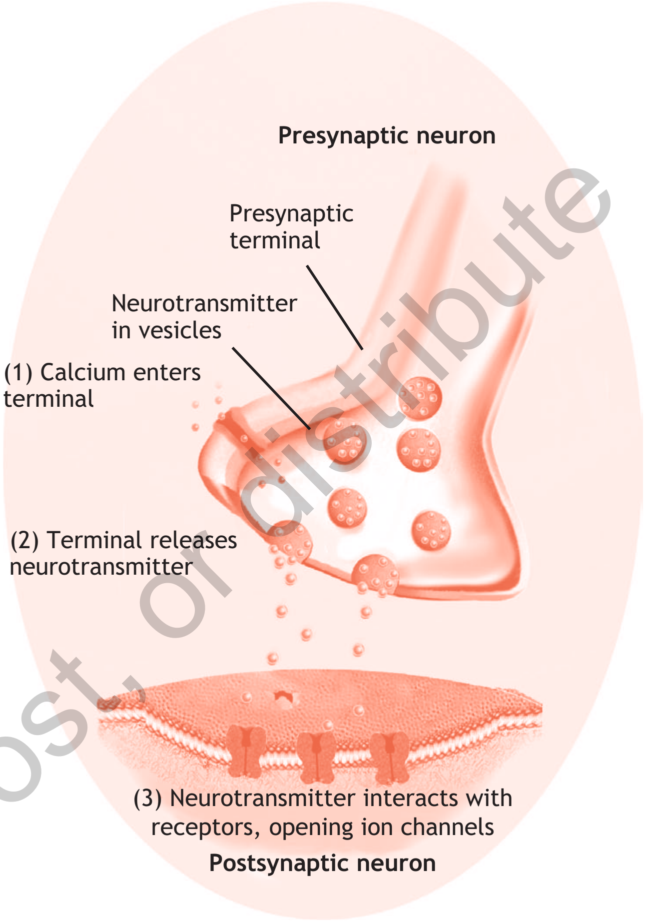
Mirror Neurons

Several decades ago, Italian scientist Giacomo Rizzolatti was doing research on motor movements in monkeys using fMRI technology (Rizzolatti et al., 1996). He discovered a set of neurons that fired both when the monkey performed an action and when it observed a similar action performed by another monkey or the experimenter. These specific neurons were named *mirror neurons* and were later discovered in humans. As with the monkeys, scientists using fMRI technology found clusters of neurons in the premotor cortex (the area in front of the motor cortex that plans movements) firing just before a person carried out a planned movement. Curiously, these neurons also fired when a person saw someone else perform the same movement. For example, the firing pattern of these neurons that preceded the subject grasping a cup of coffee was identical to the pattern when the subject saw someone else do that. Thus, similar brain areas process both the production and the perception of movement.

Neuroscientists believe these mirror neurons play an important role in social interactions and in the development of one's social skills. They may help an individual to decode the intentions and predict the behavior of others (Iacoboni, 2015; Schmidt et al., 2020). They allow us to recreate the experience of others within ourselves and to understand others' emotions and empathize. Seeing the look of disgust or joy on other people's faces causes mirror neurons to trigger similar emotions in us. We start to feel their actions and sensations as though we were doing them.

Mirror neurons begin development in the preschool brain (Dai et al., 2019). These neurons probably explain the mimicry we see in young children when they imitate our smiles and many of our other movements. We have all experienced this phenomenon when we attempted to stifle a yawn after seeing someone else yawning. Neuroscientists have wondered whether mirror neurons may explain a lot about mental behaviors that have remained a mystery. For instance, could children with autism spectrum disorder have a deficit in their mirror neuron system? Wouldn't that explain why they have difficulty inferring the intentions and mental state of others? The answer to these questions appears to be yes. Studies do suggest that deficits in the mirror neuron system are associated with autism spectrum disorder. However, therapies, such as noninvasive transcranial electric stimulation, have shown improvement in sociability, behavioral, health, and physical conditions in individuals with autism spectrum disorder, with no reported side effects, compared with the control group (Hadoush et al., 2019).

FIGURE 1.5 The neural impulse is carried across the synapse by chemicals called neurotransmitters that lie within the synaptic vesicles.



BRAIN FUEL

Brain cells consume oxygen and glucose (a form of sugar) for fuel. The more challenging the brain's task, the more fuel it consumes. Therefore, it is important to have adequate amounts of these substances in the brain for optimum functioning. Low amounts of oxygen and glucose in the blood can produce lethargy and sleepiness. Eating a moderate portion of food containing glucose (fruits are an excellent source) can boost the performance and accuracy of working memory, attention, and motor function (Kumar et al., 2016; Valentin & Mihaela, 2015).

Water, also essential for healthy brain activity, is required to move neuron signals through the brain. Low concentrations of water diminish the rate and efficiency of these signals. Moreover, water keeps the lungs sufficiently moist to allow for the efficient transfer of oxygen into the bloodstream.

Many students (and their teachers) do not eat a breakfast that contains sufficient glucose, nor do they drink enough water during the day to maintain healthy brain function. Schools should have breakfast programs and educate students on the need to have sufficient blood levels of glucose during the day. Schools should also provide frequent opportunities for students and staff to drink plenty of water. The current recommended amount is an eight-ounce glass of water a day for every 25 pounds of body weight. Thus, a person weighing around 150 pounds should drink six eight-ounce glasses of water a day.

NEURON DEVELOPMENT IN CHILDREN

Many students (and their teachers) do not eat a breakfast with sufficient glucose or drink enough water during the day for healthy brain function.

Neuron development starts in the embryo about four weeks after conception and proceeds at an astonishing rate. In the first four months of gestation, around 200 billion neurons are formed, but about half will die off during the fifth month because they fail to connect with any areas of the growing embryo. This purposeful destruction of neurons (called **apoptosis** or **synaptic pruning**) is genetically programmed to ensure that only those neurons that have made connections are preserved and to prevent the brain from being overcrowded with unconnected cells. The characteristic folds in the cerebrum begin to develop around the sixth month of gestation, creating the sulci and gyri that give the brain its wrinkled look. Smoking or drugs and alcohol that the mother takes during this time can interfere with the growing brain cells, increasing the risk of fetal addiction and mental defects.

The neurons of a newborn are immature; many of their axons lack the protective **myelin** layer, and there are few connections between them. Thus, most regions of the cerebral cortex are quiet. Understandably, the most active areas are the brain stem (body functions) and the cerebellum (movement).

Surprisingly, neurons in a child's brain make many more connections than those in adults. A newborn's brain makes connections at an incredible pace as the child absorbs stimuli from its environment. Information is entering the brain through "windows" that emerge and taper off at various times. The richer the environment, the greater the number of interconnections that are made. Consequently, learning can take place faster and with greater meaning.

As the child approaches puberty, the pace slackens, and two other processes begin: Connections the brain finds useful become permanent, and those not useful are eliminated (apoptosis) as the brain selectively strengthens and prunes connections based on experience. This process continues throughout our lives, but it appears to be most intense between the ages of 3 and 12 years. Thus, at an early age, experiences are already shaping the brain and designing the unique neural architecture that will influence how it handles future experiences in school, work, and other places.

WINDOWS OF OPPORTUNITY

Windows of opportunity represent important periods in which the young brain is highly susceptible to certain types of input from its environment in order to create or consolidate neural networks. Some windows relating to physical development are critical and are called *critical periods* by pediatric researchers. For example, if even a perfect brain does not receive visual stimuli by the age of 2, the child will be forever blind, and if a child does not hear words by the age of 12, the person will most likely never learn a known language. When these critical windows taper off, the brain cells assigned to those tasks may be pruned or recruited for other tasks.

The windows relating to cognitive and skill development are far more plastic but still significant. It is important to remember that learning can occur in each of the areas for the rest of our lives, even after a window tapers off. However, the skill level probably will not be as high. This ability of the brain to continually change during our lifetime in subtle ways as a result of experience is referred to as brain **plasticity** (also called **neuroplasticity**).

An intriguing question is why the windows taper off so early in life, especially since the average life span is now more than 75 years. One possible explanation is that these developmental spurts are genetically determined and were set in place many thousands of years ago when our life span was closer to 20 years. Figure 1.6 shows just a few of the windows that we will examine to understand their importance.

Several words of caution are necessary here. First, the notion of "windows of opportunity" should not cause parents to worry that they may have missed providing critical experiences to their children in their early years. Rather, parents and educators should remember that the brain's plasticity and resilience allow it to learn almost anything at any time, as long as the associated neural networks are developing or in place. In general, learning earlier is better, but learning later is certainly possible and not a catastrophe.

Second, the initiatives and pressures to increase teacher and school accountability in recent years have been changing what is happening in the primary grades. Early childhood researchers noted that studies of instruction and content in kindergartens showed that these classrooms were becoming more like first grade (Bassok et al., 2016). Basically, kindergarten teachers were spending time on more challenging literacy and mathematics content. However, the studies also found that this shift resulted in a decrease in time spent on music, art, science, and child-selected activities. Furthermore, there was much more frequent use of standardized testing.

The brain's plasticity and resilience allow it to learn almost anything at any time, as long as the associated neural networks are developing or in place.

Since this research surfaced several years ago, two major developments have occurred. One is the concern over the increased use of standardized testing just when the school population is becoming more diverse and thus less standardized. The other is the unexpected and profound disruption that the COVID epidemic has made to conventional schooling. We will now need to determine what impact these developments have had on the kindergartners' and primary grade students' cognitive and social development.

Motor Development

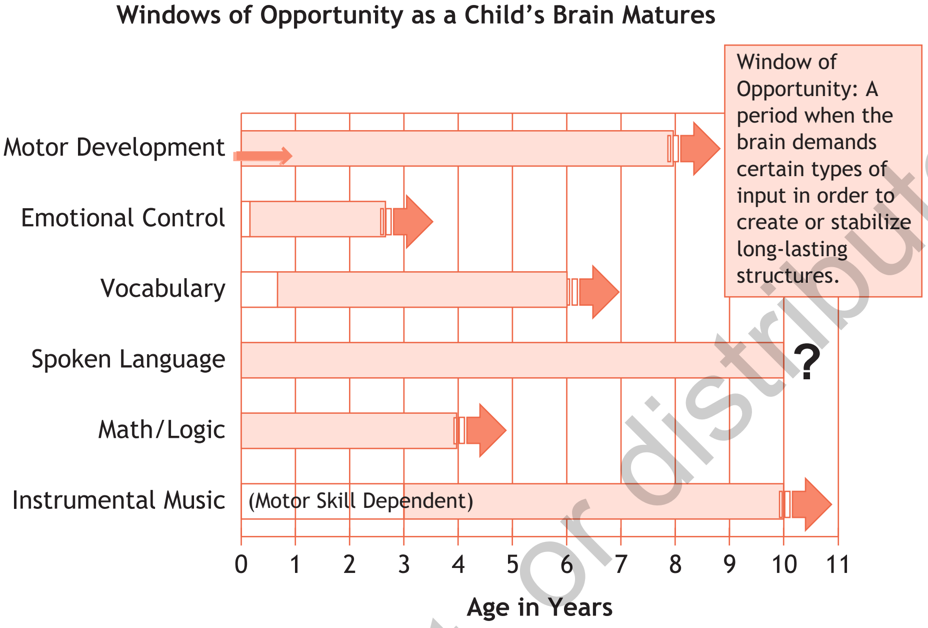
This window opens during fetal development. Those who have borne children remember all too well the movement of the fetus during the third trimester as motor connections and systems are consolidating. The child's ability to learn motor skills appears to be most pronounced in the first eight years. Such seemingly simple tasks as crawling and walking require complicated associations of neural networks, including integrating information from the balance sensors in the inner ear and output signals to the leg and arm muscles. Of course, a person can learn motor skills after the window tapers off. However, what is learned and practiced while it is open can be learned masterfully. Most concert virtuosos (e.g., cellist Yo Ma), Olympic medalists (e.g., swimmer Michael Phelps), and professional players of individual sports such as tennis (e.g., Serena and Venus Williams) and golf (e.g., Tiger Woods) began practicing their skills by the age of 8.

Emotional Control

The window for developing emotional control seems to be from 2 to 30 months. During that time, the limbic (emotional) system and the frontal lobe's rational system are evaluating each other's ability to get their owners what they want. It is hardly a fair match. Studies of human brain growth suggest that the emotional (and older) system develops faster than the frontal lobes (see Figure 1.7; Kray et al., 2020; Leventon et al., 2014; Wessing et al., 2015). Consequently, the emotional system is more likely to win the tug-of-war for control. If tantrums almost always get the child satisfaction when the window is open, then that is the method the child will likely use when the window tapers off.

What is learned and practiced while a window of opportunity is open can be learned masterfully.

FIGURE 1.6 The chart shows some of the sensitive periods for learning during childhood, according to current research. Future studies may modify the ranges shown in the chart. It is important to remember that learning occurs throughout our entire life.



This constant emotional–rational battle is one of the major contributors to the "terrible twos." Certainly, one can learn to control emotions after that age. But what the child learned during that open-window period will be difficult to change, and it will strongly influence what else is learned after the window tapers off.

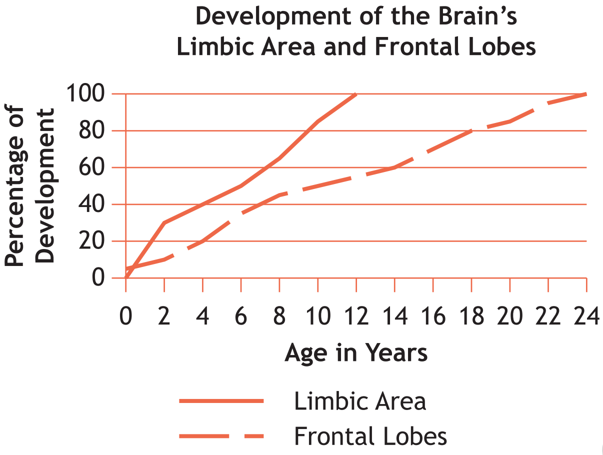
In an astonishing example of how nurturing can influence nature, there is considerable evidence confirming that how parents respond to their children emotionally during this time frame can encourage or stifle genetic tendencies. Biology is not destiny, so gene expression is not necessarily inevitable. To produce their effects, genes must be turned on. The cells on the tip of your nose contain the same genetic code as those in your stomach lining. But the gene that codes for producing stomach acid is activated in your stomach, yet idled on your nose. For example, shyness is a trait that seems to be partially hereditary. If parents are overprotective of their bashful young daughter, the toddler is likely to remain shy. On the other hand, if they encourage her to interact with other toddlers, she may overcome it. Thus, genetic tendencies toward intelligence, sociability, or schizophrenia and aggression can be ignited, moderated, or stifled by parental response and other environmental influences (Cheng & Furnham, 2020; McNamara & Isles, 2014; Zheng & Cleveland, 2015). See Chapter 9 for more information on social-emotional learning.

The struggle between the emotional and rational systems is a major contributor to the "terrible twos."

Social Skills

We noted earlier that mirror neurons start developing in the toddler years. These cerebral regions responsible for social behavior mature faster than either the emotional system, which usually matures between the ages of 10 and 12 years, or the rational (cognitive)

FIGURE 1.7 **Based on research studies, this chart suggests the possible degree of development of the brain's limbic area and frontal lobes. The 10-to 12-year lag in the full development of the frontal lobes (the brain's rational system) explains why so many adolescents and young adults get involved in risky situations.**



system, which usually matures between the ages of 22 and 24 years. This research is clearly reminding educators and parents that they should not expect social, emotional, and cognitive abilities to develop at the same rate as children grow up. Social competencies will appear early, followed by emotional competencies. The cognitive competencies will emerge later. This staggered maturation implies that developing social competencies should begin in the preschool years, recognizing that emotional and cognitive development are still in their early stages. See Chapter 9 for additional information on social-emotional learning.

Of timely concern regarding social skills development is the impact of technology. Because of the increased amount of time that children are interacting with digital devices at such an early age, researchers are studying how these interactions are affecting the development of the mirror neurons system. One potential negative impact is that the anonymity of the internet may ultimately limit the children's ability to develop empathy, especially as they move into middle and high school where digital texting and social media are widespread (Laidlaw et al., 2019).

Vocabulary

Because the human brain is genetically predisposed for language, babies start uttering sounds and babble nonsense phrases as early as the age of 2 months. By the age of 8 months, infants begin to try out simple words like "mama" and "dada. "The language areas of the brain become really active at 18 to 20 months. A toddler can learn 10 or more words per day, yielding a vocabulary of about 900 words at age 3 years, increasing to 2,500 to 3,000 words by the age of 5.

Here's testimony to the power of talk: Researchers have shown that babies whose parents, especially fathers, talked to them more had significantly larger vocabularies (Conica et al., 2020; Henderson et al., 2013). Knowing a word is not the same as understanding its meaning, so it is crucial for parents to encourage their children to use new words in a context that demonstrates they know what the words mean. Children who know the meaning of most of the words in their large vocabulary will start school with a greater likelihood that learning to read will be easy and quick. These positive findings hold even for children from low-income families (Malin et al., 2014).

Language Acquisition

The newborn's brain is not the *tabula rasa* (blank slate) we once thought. Certain areas are specialized for specific stimuli, including spoken language. The window for acquiring spoken language opens soon after birth and tapers off first around the age of 5 years and again around the age of 10 to 12 years. Beyond that age, learning any language becomes more difficult. The genetic impulse to learn language is so strong that even children found in feral environments often make up their own language. Furthermore, the very young brain can easily acquire two or more languages simultaneously in a supportive multilingual environment. Knowing this, it seems illogical that many schools still wait to *start* new language instruction in middle school or high school rather than in the primary grades. Chapter 5 deals in greater detail with how the brain acquires spoken language.

Mathematics and Logic

How and when the young brain understands numbers is uncertain, but there is substantial evidence that infants have a rudimentary number sense that is wired into certain brain sites at birth (Ceulemans et al., 2015; Dehaene, 2010; Whitacre et al., 2020). The purpose of these sites is to categorize the world in terms of the "number of things" in a collection; that is, they can tell the difference between two of something and three of something. We drive along a road and see horses in a field. While we are noticing that they are brown and black, we cannot help but realize that there are four of them, even though we did not count them individually. Researchers have also found that toddlers as young as 2 years recognize the relationships between numbers as large as *4* and *5*, even though they are not able to verbally label them. This research shows that fully functioning language ability is not needed to support fundamental number sense, but it is necessary to do numerical calculations (King & Purpura, 2021; Lachmair et al., 2014). More about how the brain learns mathematics appears in Chapter 6.

Instrumental Music

All cultures create music, so we can assume that it is an important part of being human. Babies respond to music as early as 2 to 3 months of age. A window for creating music may be open at birth, but obviously neither the baby's vocal cords nor motor skills are adequate to sing or to play an instrument. Around the age of 3 years, most toddlers have sufficient manual dexterity to play a piano (Mozart was playing the harpsichord and composing at age 4). Several studies have shown that children aged 3 to 4 years who received piano lessons scored significantly higher in spatial-temporal tasks than a group who did not get the instrumental music training. Further, the increase was long term (Vargas, 2015). Brain imaging reveals that creating instrumental music excites the same regions of the left frontal lobe responsible for mathematics, logic, and other cognitive processes (Van de Cavey & Hartsuiker, 2016). See Chapter 7 for more on the effects of music on the brain and learning.

Research on how the young brain develops suggests that an enriched home and preschool environment during the early years can help children build neural connections and make full use of their mental abilities. Because of the importance of early years, I believe school districts should communicate with the parents of newborns and offer their services and resources to help parents succeed as the first teachers of their children. Such programs, called "parents as teachers" initiatives, are already in place on a statewide basis in several states, and similar programs sponsored by local school districts are springing up elsewhere. The Every Student Succeeds Act places great emphasis on the importance of early childhood education. But we need to work faster toward achieving this important goal.

THE BRAIN AS A NOVELTY SEEKER

School districts should communicate with the parents of newborns and offer their services and resources to help parents succeed as the first teachers of their children.

Part of our survival and success as a species can be attributed to the brain's persistent interest in *novelty*—that is, changes occurring in the environment. The brain is constantly scanning its environment for stimuli to determine whether they pose a potential threat. When an unexpected stimulus arises—such as a loud noise from an empty room—a rush of adrenaline closes down all unnecessary activity and focuses the brain's attention so it can assess the stimulus and be ready to spring into action and protect its owner. Conversely, an environment that contains mainly predictable or repeated stimuli (like some classrooms?) lowers the brain's interest in the outside world and tempts it to turn within for novel experiences.

ENVIRONMENTAL FACTORS THAT ENHANCE NOVELTY

Experienced teachers often remark about how different today's students are from those of just a few years ago. They arrive with all their electronic gadgets and their attention darting among many tasks—usually not involving mathematics. Many teachers have incorporated more technology into their lessons, mainly because that holds the students' attention. In the past, teachers reacted skeptically whenever I talked to them about the rapidly increasing research findings about the brain and their possible applications to teaching and learning. Not anymore! The teachers now realize that, because the brain of today's student is developing in a rapidly changing environment, they must adjust their teaching.

We often hear teachers remark that students are more different today in the way they learn than ever before. They seem to have shorter attention spans and get bored easily. Why is that? Is there something happening in the environment of learners that alters the way they approach the learning process? In a word, yes!

In recent years, children have been growing up in a rapidly changing environment.

- Family units now come in many different arrangements, some of them a result of restrictions brought on by the COVID pandemic.
- Many 10- to 18-year-olds can now watch television and play with other technology in their own bedrooms, leading to serious sleep deprivation. Furthermore, with no adult present, what kind of moral compass is evolving in the impressionable preadolescent mind as a result of watching programs containing violence and sex on television and the internet?
- This group gets information from many different sources besides school, some of it inaccurate or false.
- They spend much more time indoors with their technology, thereby missing outdoor opportunities to develop gross motor skills and socialization skills necessary to communicate and act directly and civilly with others. Sometimes, their social media sites are places for hurtful antisocial expression. One unintended consequence of spending so much time indoors is the rapid rise in the number of overweight children and adolescents, now more than 19 percent of 2- to 19-year-olds. That represents 14.4 million children and adolescents (Fryar et al., 2020).
- Because of neuroplasticity, young brains have responded to technology by changing their function and organization to accommodate the large amount of stimulation occurring in the environment (Sousa, 2016). By acclimating themselves to these changes, brains respond more than ever to the unique and different—what we have called novelty. There is a dark side to this increased novelty-seeking behavior. Some

adolescents who perceive little novelty in their environment may turn to alcohol or mind-altering drugs, such as ecstasy and amphetamines, for stimulation. This drug dependence can further enhance the brain's demand for novelty to the point where it becomes unbalanced and resorts to extremely risky behavior.

- Children's diets contain increasing amounts of substances that can affect brain and body functions. Caffeine is a strong brain stimulant, considered safe for most adults in small quantities. But caffeine is found in many of the foods and drinks that teens consume daily. Too much caffeine causes insomnia, anxiety, and nausea. Some teens can also develop allergies to aspartame (an artificial sugar found in children's vitamins and many "lite" foods) and other food additives. Possible symptoms of these allergic reactions include hyperactivity, difficulty concentrating, and headaches (Sharma et al., 2015).

How Is Technology Affecting the Student's Brain?

Students today are surrounded by technology: cell phones, smartphones, multiple televisions, MP3 players, movies, computers, video games, iPads, email, and social media sites. In a 2019 survey of more than 2,600 8- to 18-year-olds, tweens 8 to 12 years old averaged almost five hours of daily media use, while teens 13 to 18 years old averaged more than seven hours of media use per day (Common Sense Media, 2019). In other words, teens spend more time using media than they do sleeping or interacting with their teachers and parents. Technology has become the dominant factor in their lives, and because of neuroplasticity, it is rewiring their brains.

Effect on Attention. The multimedia environment divides their attention. Even newscasts are different. In the past, only the reporter's face was on the screen. Now the TV screen is loaded with information. Three people are reporting in from different corners of the world. Additional nonrelated news is scrolling across the bottom, and the stock market averages are changing in the lower right-hand corner just below the local time and temperature. These tidbits are distracting and are forcing viewers to split their attention into several components. They may miss a reporter's comment because a scrolling item caught their attention. Yet children have become accustomed to these information-rich and rapidly changing messages. They can shift their attention quickly among several things, but their brains can still focus on only one thing at a time.

The Myth of Multitasking. Sure, we can walk and chew gum at the same time because they are separate physical tasks requiring no measurable cognitive input. However, the brain cannot carry out two cognitive processes simultaneously. Our genetic predisposition for survival directs the brain to focus on just one item at a time to determine whether it poses a threat. If we were able to focus on several items at once, it would dilute our attention and seriously reduce our ability to make the threat determination quickly and accurately.

What we refer to as multitasking is actually **task switching**. It occurs as sequential tasking (attention moves from Item A to Item B to Item C, etc.) or alternate tasking (attention moves between Items A and B). Whenever the brain shifts from focusing on Item A to focusing on Item B and back again to Item A, there is a cognitive loss involved. Figure 1.8 illustrates the process that will unfold in the following example. The solid graph line represents the amount of working memory used to process a homework task, and the dotted graph line represents the amount used to process an incoming phone call. Let us say Jeremy is a high school student who is working on a history assignment and has just spent 15 minutes focusing on understanding the major causes of World War II. The thinking part of his brain (frontal lobe) is working hard, and a significant amount of working memory is processing this information.

Suddenly, the cell phone rings. Caller ID shows him that the call is from his girlfriend, Donna. Now his emotional brain (limbic area) is awakened. As he answers the phone, his brain must disengage from processing history information to recalling the steps to answering and attending to an important phone call. Jeremy spends the next six minutes chatting with Donna. During that time, much of the World War II information that Jeremy's working memory was processing begins to fade as it is replaced by information from the phone call (working memory has a limited capacity). When Jeremy returns to the assignment, it is almost like starting all over again. The memory of having worked on the assignment may cause the student to believe that all the information is still in working memory, but much of it is gone. He may even mumble, "OK, where was I?" Task switching always incurs a price (Madore & Wagner, 2019).

The brain cannot multitask. It can focus on only one task at a time. Alternating between tasks always incurs a loss.

Task Switching and Complex Texts. Living in a world in which task switching is the norm may be affecting students' ability to read and concentrate on complex texts. Results of the 2019 ACT tests, taken by nearly 1.8 million high school students, showed that only 45 percent met the ACT college readiness benchmarks for reading (ACT, 2019). These benchmarks include the ability to comprehend complex texts. These texts usually contain high-level vocabulary and elaborate grammatical structure as well as literal and implied meanings.

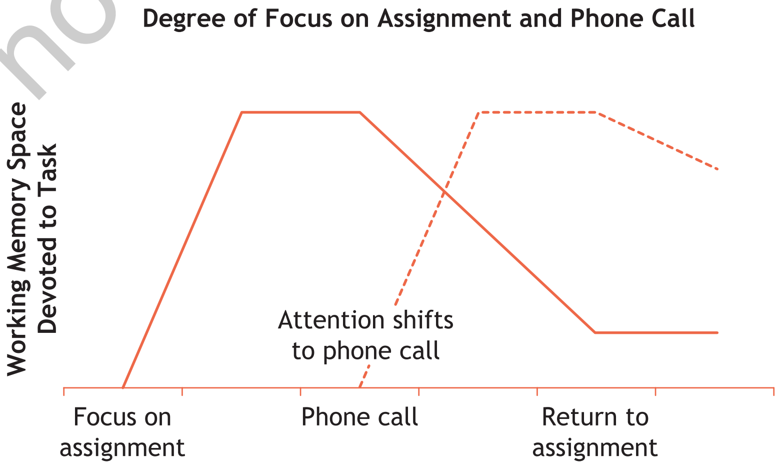
Is it possible that high school students have become so adapted to task switching that they have not developed the cognitive discipline necessary to read complex texts?

Technology is neither a panacea nor an enemy: It is a tool. Students in the primary and middle school grades still need personal contact and interaction with their teachers and peers. This is an important part of social development, but technology, perhaps to a great extent, is reducing the frequency of these interactions. We should not be providing technology for technology's sake, nor should the technology be an end unto itself. Rather than teaching with the various technologies, teachers should use them to enhance, enrich, and present their content more efficiently. Many internet sites offer free materials to help teachers expand their lessons with audio and video pieces. See the Resources section at the end of this book for some suggested sites.

Have Schools Changed With the Environment?

Many educators are recognizing the characteristics of the new brain, but they do not always agree on what to do about it. Typical teenagers at home are constantly switching with ease

FIGURE 1.8 **When an assignment is interrupted by a phone call, memory resources dedicated to the assignment (solid line) decline, and resources dealing with information from the phone call (dotted line) increase.**



among their MP3 player, cell phone, laptop, video games, and television. Multimedia is all around them. Can we then expect them to sit quietly for 30 to 50 minutes listening to the teacher, filling in a worksheet, or working alone? Granted, teaching methodologies are changing, and teachers are using newer technologies and even introducing pop music and culture to supplement traditional classroom materials. But schools and teaching are not changing fast enough. In high schools, lecturing continues to be the main method of instruction, primarily because of the vast amount of required curriculum material and the pressure of increased accountability and high-stakes testing. Students remark that school is a dull, nonengaging environment that is much less interesting than what is available outside school. Despite the recent efforts of educators to deal with this new brain, many high school students still do not feel challenged.

A 2009 to 2018 survey of more than 450,000 students in Grades 6 to 12 revealed that 44 percent thought "school is boring," while only 42 percent felt that "teachers make school an exciting place to learn" (Quaglia Institute, 2019).

The Importance of Exercise. Just think about some of the things we do in schools that run counter to what we know about how the brain learns. One simple but important example is the notion of exercise. Exercise increases blood flow to the brain and throughout the body. The additional blood in the brain is particularly effective in the hippocampus, an area deeply involved in forming long-term memories. Exercise also triggers one of the brain's most powerful chemicals, a tongue twister called brain-derived neurotrophic factor (BDNF). This protein supports the health of young neurons and encourages the growth of new ones. Once again, the brain area that is most sensitive to this activity is the hippocampus. Studies show that increased physical activity in school leads to improved student attention and academic performance (Álvarez-Bueno et al., 2017). Yet students still sit too much in school, especially in high school, and elementary schools are reducing or eliminating recess to devote more time to preparing for high-stakes testing. In other words, we are cutting out the very activity that could improve cognitive performance on these tests.

As we continue to develop a more scientifically based understanding about today's novel brain, we must decide how this new knowledge should change what we do in schools and classrooms.

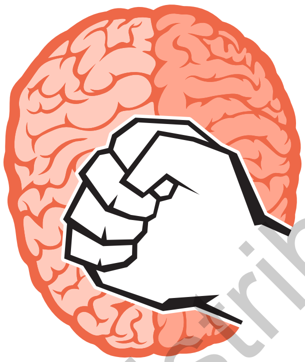
Clearly, the COVID pandemic has forced educators to rethink how we adjust for the uncertain future. And whatever adjustments we make must accommodate and maintain the interest of this new brain. As we continue to develop a more scientifically based understanding about today's novel brain and how it learns, we must decide how this new knowledge should change what we do in schools and classrooms.

WHAT'S COMING UP?

Now that we have reviewed some basic parts of the brain and discussed how the brain of today's student has become acclimated to novelty, the next step is to look at a model of how the brain processes new information. Why do students remember so little and forget so much? How does the brain decide what to retain and what to discard? The answers to these and other important questions about brain processing will be found in the next chapter.

PRACTITIONER'S CORNER

Fist for a Brain



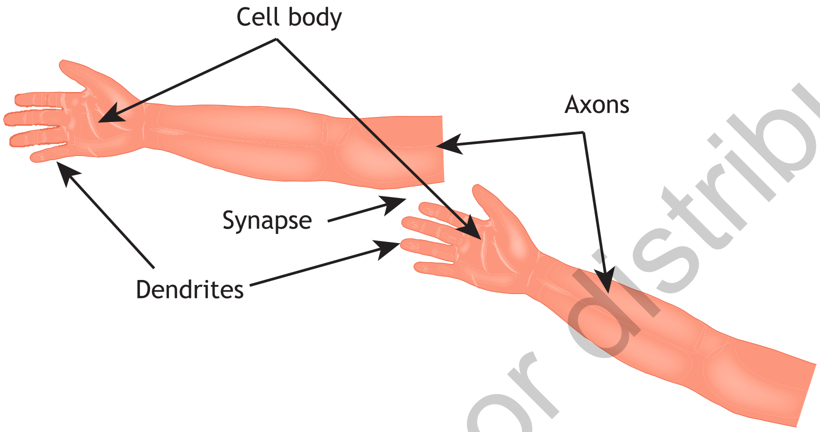
This activity shows how you can use your fists to represent the human brain. Metaphors are excellent learning and remembering tools. When you are comfortable with the activity, share it with your students. They are often very interested in knowing how their brain is constructed and how it works. This is a good example of novelty.

1. Extend both arms with palms open and facing down and lock your thumbs.
2. Curl your fingers to make two fists.
3. Turn your fists inward until the knuckles touch.
4. While the fists are touching, pull both toward your chest until you are looking down on your knuckles. This is the approximate size of your brain! Not as big as you thought? Remember, it's not the size of the brain that matters; it's the number of connections between the neurons. Those connections form when stimuli result in learning. The thumbs are the front and are crossed to remind us that the left side of the brain controls the right side of the body and that the right side of the brain controls the left side of the body. The knuckles and outside part of the hands represent the *cerebrum*, or thinking part of the brain.
5. Spread your palms apart while keeping the knuckles touching. Look at the tips of your fingers, which represent the *limbic*, or emotional, area. Note how this area is buried deep within the brain and how the fingers are mirror imaged. This reminds us that most of the structures of the limbic system are duplicated in each hemisphere.
6. The wrists are the *brain stem* where vital body functions (e.g., body temperature, heartbeat, blood pressure) are controlled. Rotating your hands shows how the brain can move on top of the spinal column, which is represented by your forearms.

PRACTITIONER'S CORNER

Arm for a Neuron

This activity shows how the human arm can be used to represent the structure of a neuron in the brain.

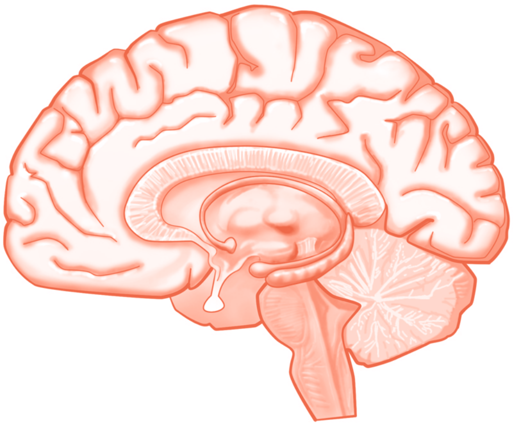


FOREARM IMAGE: ©iStockphoto.com/Medical Art, Inc.

Using the diagrams above, students can point out on their own arms the parts that represent major structures in the neuron. The palm is the cell body, the arm is the axon, and the fingers are the dendrites. The area where the finger on one student's hand almost touches another student's arm represents the synapse.

PRACTITIONER'S CORNER

Review of Brain Area Functions



Here is an opportunity to assess your understanding of the major brain areas. Write in the table below your own key words and phrases to describe the functions of each of the eight brain areas. Then draw an arrow to each brain area on the diagram and label it.

Amygdala:
Brain Stem:
Cerebellum:
Cerebrum:
Frontal Lobe:
Hippocampus:
Hypothalamus:
Thalamus:

PRACTITIONER'S CORNER

Using Novelty in Lessons

Using novelty does *not* mean that the teacher needs to be a stand-up comic or the classroom a three-ring circus. It simply means using a varied teaching approach that involves more student activity. Here are a few suggestions for incorporating novelty in your lessons.

- **Humor.** There are many positive benefits that come from using humor in the classroom at all grade levels. See the Practitioner's Corner: Using Humor to Enhance Climate and Promote Retention in Chapter 2, which suggests guidelines and beneficial reasons for using humor.
- **Movement.** When we sit for more than 20 minutes, our blood pools in our seat and in our feet. By getting up and moving, we recirculate that blood. Within a minute, there is about 15 percent more blood in our brain. We do think better on our feet than on our seat! Students sit too much in classrooms, especially in secondary schools. Look for ways to get students up and moving, especially when they are verbally rehearsing what they have learned.
- **Multisensory Instruction.** Today's students are acclimated to a multisensory environment. They are more likely to pay attention if there are interesting, colorful visuals; if they can interact with appropriate technology; and if they can walk around and talk about their learning.
- **Quiz Games.** Have students develop a quiz game or another similar activity to test each other on their knowledge of the concepts taught. This is a common strategy in elementary classrooms but is underused in secondary schools. Besides being fun, it has the added value of making students rehearse and understand the concepts in order to create the quiz questions and answers.
- **Music.** Although the research is inconclusive, there are some benefits of playing music in the classroom at certain times during the learning episode. See the Practitioner's Corner: Using Music in the Classroom in Chapter 6.

PRACTITIONER'S CORNER

Preparing the Brain for Taking a Test

Taking a test can be a stressful event. Chances are your students will perform better on a test of cognitive or physical performance if you prepare their brains with one of the following:

- **Exercise.** Get the students up to do some exercise for just two minutes. Jumping jacks are good because the students stay in place. Students who may not want to jump up and down can do five brisk round-trip walks along the longest wall of the classroom. The purpose here is to get the blood oxygenated and moving faster.
- **Fruit.** Besides oxygen, brain cells also need glucose for fuel. Fruit is an excellent source of glucose. Students should eat about two ounces (more than 50 grams) of fruit each day. Dried fruit, such as raisins, is convenient. Avoid fruit drinks as they often contain just fructose, a fruit sugar that does not provide immediate energy to cells. Studies show that ingesting glucose can improve cognitive performance (e.g., Smith et al., 2011).
- **Water.** Wash down the fruit with an eight-ounce glass of water. The water gets the sugar into the bloodstream faster and hydrates the brain.

Wait about five minutes after these steps before giving the test. That should be enough time for the added glucose to fire up the brain cells. The effect lasts for only about 30 minutes, so the steps need to be repeated periodically for longer tests.

CHAPTER 1: BASIC BRAIN FACTS

KEY POINTS TO PONDER

Jot down on this page key points, ideas, strategies, and resources you want to consider later. This sheet is your personal journal summary and will help to jog your memory.