Preface

I always enjoy writing and updating *Human Learning*. Each passing year brings exciting new research findings about how human beings think and learn. As a result, each year also brings new strategies for helping learners of all ages acquire information and skills—as well as beliefs, motives, and attitudes—that will be useful and productive both inside and outside the classroom. As you explore the nature of human learning in the pages ahead, I hope that my fascination with the topic will be contagious.

I've written this book with particular readers in mind: those who would like to learn about learning but don't necessarily have much background in psychology. Such readers may benefit from studying the historical roots of learning theories but prefer to focus their energies on studying contemporary perspectives and ideas. These readers might find learning theories fascinating but lose patience when they can't see much relevance of the theories to everyday practice. They don't want to be overwhelmed by the many nit-picky sources of disagreement among theorists who, for the most part, are explaining human learning and thinking processes in very similar ways. And they're quite capable of reading a dry, terse textbook but probably learn more effectively from a book that shows how different concepts relate to one another; provides numerous examples; and, especially, emphasizes meaningful learning—true *understanding*—of the material it presents.

New to This Edition

Users of the sixth edition will see a great many changes in this seventh edition. As I always do, I've updated the text in innumerable spots to reflect current theoretical perspectives and research findings regarding cognition, learning, and instructional practices. I've also increased coverage of technology-based interventions in several chapters. And I've worked hard to tighten my prose, eliminating needless redundancies and clarifying spots that struck me as awkward or ambiguously worded.

A more noticeable change is a reduction of the sixth edition's 17 chapters into 15 chapters. The three previous behaviorism chapters are now only two, "Behaviorist Principles and Theories" (Chapter 3) and "Applications of Behaviorist Principles" (Chapter 4), with considerable

reorganization of topics. In addition, the two previous chapters on long-term memory storage and retrieval have been combined into a single chapter, "Long-Term Memory Storage and Retrieval Processes" (Chapter 8), with deletion of some ideas and examples that were probably "TMI"—too much information.

Furthermore, consistent with our ever-evolving understanding of human learning, I've added or expanded on a number of topics, and I've deleted a handful of topics that, again, were probably TMI. Following are notable examples:

- *Chapter 1:* New (brief) discussion of different types of learning research (per reviewer requests); updated discussion of how theories have evolved over time to incorporate other contextual views and neuroscience; expansion of Figure 1.2 to portray new theoretical orientations on the scene.
- *Chapter 2:* New discussion of adolescent risk taking in the section on brain development; new discussion of heredity/environment interactions in brain development; new bullet regarding the importance of sleep and exercise.
- *Chapter 3 (integration of parts of the former Chapters 3 and 4):* Discussion of classical conditioning in television commercials (per reviewer request); switch back to the term *operant conditioning* in the discussion of reinforcement, with the term *instrumental conditioning* being introduced in a subsequent section on punishment; deletion of sections on sensory preconditioning and Guthrie's (1935) strategies for breaking habits; explanation of what *reinforcement* means in classical conditioning (per reviewer request); token reinforcers added as a new bulleted item to the section on positive reinforcement.
- *Chapter 4 (formerly Chapter 5, with the addition of some content from the former Chapter 3):* Inclusion of Common Core in the section on instructional objectives; new section on assessment practices from a behaviorist perspective, with relevant discussions of high-stakes tests, backward design, and rubrics.
- *Chapter 5 (formerly Chapter 6):* Revision of "emotional state" to "physiological state" as a factor affecting self-efficacy, to represent more accurately Bandura's (1997) discussion of this factor; addition of effortful control as an individual difference variable in self-regulation; addition of self-videos as a strategy for self-monitoring; new bulleted section on teacher self-efficacy.
- *Chapter 6 (formerly Chapter 7):* Movement of general assumptions to beginning of chapter, to be parallel to the organization of Chapters 3 and 5; more explicit ties of cognitivist ideas to social cognitive theory.
- *Chapter 7 (formerly Chapter 8):* Expansion of the discussion of the central executive, with a subheading to enhance its visibility in the chapter; discussion of effortful control here as well as in Chapter 5; expanded discussion of long-term memory's permanence or non-permanence (moved from the old Chapter 11); introduction of the concept *cognitive load,* which has been alluded to but not specifically labeled in previous editions; enhanced discussion of how to help students direct their attention in beneficial ways, including the issue of choosing productive links in websites and instructional software; new bullet regarding the possible value of computer-based strategies for enhancing attention and working memory capacity (note my use of the word *possible,* because the jury's still out on the viability of such approaches).
- *Chapter 8 (formerly Chapters 9 and 11):* Content condensed, with some content being moved into Chapter 7; reorganization of content to minimize redundancies; critique of the literature on learning styles (in a footnote).

- *Chapter 9 (formerly Chapter 10):* Addition of a possible neurological explanation for the difficulty of undergoing significant conceptual change; new discussion of multiple-choice formative assessment tasks as a way of encouraging conceptual change.
- *Chapter 10 (formerly Chapter 12):* Addition of cognitive load as an issue in inquiry learning.
- *Chapter 11 (formerly Chapter 13):* New discussion of communities of practice; concept of legitimate peripheral participation (formerly in a footnote) brought into the body of the text; expanded discussion of other contextualist views, with headings and a new section and figure on Bronfenbrenner's ecological systems theory; new bullet regarding technology-based strategies for scaffolding performance and/or providing virtual realistic settings for skill development; expanded discussion of technology-based collaborative learning.
- *Chapter 12 (formerly Chapter 14):* New discussion of metacognitive skills and strategies important for hypertext and the Internet; expansion of what co-regulated learning might involve; reduced overlap with discussion of effective storage processes in what is now Chapter 8; deletion of the keyword mnemonic for remembering dates and other numbers (because very few people actually use it); expanded discussion of epistemic beliefs; inclusion of *Betty's Brain* as an example of technology-based metacognitive scaffolding.
- *Chapter 13 (formerly Chapter 15):* Addition of the concept *adaptive expertise* in the discussion of transfer and problem solving; expanded discussion of possible scaffolds for student problem solving, with a focus on technology-based supports (e.g., intelligent tutors); expanded discussion of authentic activities, including a new bullet on technology-based semi-authentic activities; new figure illustrating how a multiple-choice question might assess transfer; expanded discussion of critical thinking.
- *Chapter 14 (formerly Chapter 16):* Expanded discussion of situated motivation to emphasize person–environment interactions; heavier emphasis on the term *autonomy* (rather than on *self-determination*), in line with most contemporary writings about this topic; expansion of the section on the need for relatedness to include the need for belonging and the sixth edition's material on the need for affiliation; new section on one's sense of identity as an individual difference variable in motivation; addition of *adaptability* to the discussion of dispositions; new discussion of boredom as an affective state.
- *Chapter 15 (formerly Chapter 17):* Expanded discussion of interest to include sociocultural influences on its development; expansion of section on work-avoidance goals to include doing-just-enough goals; addition of *emotion regulation* as a key term in the section on self-regulation; new discussion of epistemic beliefs on student-identified goals in a learning activity.

Acknowledgments

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Jeanne Ellis Ormrod

CHAPTER 1

PERSPECTIVES ON LEARNING

LEARNING OUTCOMES

1.1. Explain what learning is and various ways in which it might be manifested in a person's behavior.

1.2. Briefly describe several types of research that psychologists have conducted to investigate the nature of learning.

1.3. Distinguish between principles and theories of learning, and explain how both principles and theories can guide the development of effective instructional and therapeutic interventions.

1.4. Describe various theoretical perspectives of learning that have emerged and evolved since the early 1900s.

When my son Alex was in kindergarten, his teacher asked me *please* to do something about his shoes. I had been sending Alex to school each morning with his shoelaces carefully tied, yet by the time he arrived at his classroom door, the laces were untied and flopping every which way—a state to which they invariably returned within 10 minutes of his teacher's retying them. Although I had given Alex numerous shoe-tying lessons, the step-by-step procedure I had taught him never seemed to "stick." I then suggested that we double-knot the laces each morning, but Alex rejected this strategy as too babyish. As an alternative, I purchased a couple of pairs of shoes with Velcro straps instead of laces, but Alex gave the shoes such a workout that the Velcro quickly separated from the leather, and so we went back to laces. By March, his exasperated teacher was insisting that Alex learn how to tie his shoes. So I sat down with him and demonstrated, for the umpteenth time, how to put two laces together to make a presentable bow. This time, however, I accompanied my explanation with a magical statement: "Alex, when you learn to tie your shoes, I'll give you a quarter." His eyes lit up, and he had shoe-tying perfected in five minutes. After that, we didn't have a single complaint from school—well, at least not about his shoes.

When my daughter Tina was in fourth grade, she felt considerable frustration with a series of homework assignments in subtraction. She had never learned the basic subtraction facts, despite my continually nagging her to practice them, the result being that she couldn't solve many two- and three-digit subtraction problems. One night, after her typical half-hour tantrum about

"these stupid problems," my husband explained to Tina that subtraction was nothing more than reversed addition and that her knowledge of addition facts could help her with subtraction. Something must have clicked in Tina's head, because we weren't subjected to any more tantrums about subtraction. Multiplication and division continued to be problematic for her—and don't get me started about the fractions that came later—but at least she had unraveled the mystery of subtraction.

Human learning takes many forms. Some instances of learning are readily observable, such as when a child learns to tie shoes. Other instances may lie below the surface, such as when a child gains a better understanding of mathematical principles. And people learn for a variety of reasons. Some learn for the external rewards their achievements bring—for example, for good grades, recognition, or money. But others learn for less obvious, more internal reasons—perhaps to gain a sense of accomplishment and satisfaction, or perhaps simply to make their lives easier.

The Importance of Learning

Many species have things easy compared to human beings, or at least so it would seem. Birds, for example, are born with a wealth of knowledge that we humans must learn. They seem to be biologically hardwired with home-building skills; we either have to be taught something about framing, roofing, and dry walling or must hire someone else to do these things for us. Birds know, without being taught, exactly when to fly south and how to get there; we have to look at calendars and road maps. Birds instinctively know how to care for their young; meanwhile, we attend prenatal classes, read child-care books, and watch other people demonstrate how to change diapers.

Yet we human beings—not birds—are the ones getting ahead in this world. We have learned to make increasingly sturdy and comfortable homes, developed increasingly expedient modes of transportation, and are feeding and caring for our offspring so well that each generation grows taller, stronger, and healthier than the preceding one. Birds, meanwhile, are living the same primitive lifestyles they've had for centuries.

The ability to acquire a large body of knowledge and a wide variety of behaviors allows the human race a greater degree of flexibility and adaptability than is true for any other species on the planet. Because so little of our behavior is instinctive and so much of it is learned, we're able to benefit from our experiences. We discover which actions are likely to lead to successful outcomes and which are not, and we modify our behaviors accordingly. And as we pass on to children the wisdom we've gained from our ancestors and from our own experiences, each generation becomes just that much more capable of behaving intelligently.

To be sure, many nonhuman species learn a great deal over the course of their lifetimes. Our family dog Tobey learned that his dinner was usually served around 4 o'clock and that having a leash attached to his collar meant that a walk was imminent. Our cat Geisha learned that her litter box was in the laundry room and that a loud hiss could effectively dissuade a human from picking her up when she wasn't in the mood for cuddling. When I planted blueberry bushes outside my office window one summer, the neighborhood birds quickly discovered that the bushes were an abundant source of food and that the aluminum pie plates I hung to scare them away weren't going to do them any harm.

The more I observe and read about nonhuman animals, the more I become convinced that we humans greatly underestimate their intelligence and ability to learn. As an example, look at

Figure 1.1
Fifteen-year-old Somjai's painting of an elephant.

the painting in Figure 1.1. I watched 15-year-old Somjai paint it when I visited the Maetaman Elephant Camp in Thailand in 2006. Somjai clearly knew how to paint an elephant. What was most remarkable about this fact was that Somjai *was* an elephant. In 2006, Somjai was painting only pictures very similar to the one I show you here, but when I returned to the camp in 2008, he had expanded his repertoire considerably and could also paint an elephant grabbing a tree branch or shooting a basketball into a basket (elephant basketball was big at the camp). And the asking price for Somjai's work had skyrocketed from 20 dollars (the price I paid in 2006) to 100 dollars. A few years later, Somjai's paintings (all of elephants) were selling online for 600 to 700 dollars.

But there seem to be limits to what nonhuman species can learn. For instance, only a very small percentage of elephants become skillful painters like Somjai, and they do so only after intensive training (you can find several videos of elephant painters on YouTube). Furthermore, their artistic repertoires seem to be largely restricted to elephants, flowers, trees, and perhaps a few simple background details (e.g., notice the mountains in Somjai's painting). Many elephants reportedly have little inclination for painting at all, and most of those that do paint can make only random strokes on the canvas.

In contrast to Somjai and his talented peers, most human beings can paint not only elephants and plants but an infinite number of other things as well, often without having had much training or guidance. Painting is, for humans, not simply executing a specific sequence of brush strokes. Instead, people seem to be guided by internal "somethings"—perhaps a mental image of an elephant or flower, and probably some general strategies for representing physical entities on paper—and they can adapt those somethings quite flexibly in their various artistic endeavors.

Thus, we human beings seem to inherit an ability to think and learn in ways that nonhumans cannot. The particular environment in which we live has a huge impact on the knowledge and skills we do and don't acquire, of course, but our capacity to be versatile and adapt to many *different* situations and environments far exceeds that of other animal species.

Defining Learning

Alex's learning to tie his shoes and Tina's learning the addition–subtraction relationship are both examples of human learning. Consider these additional examples:

- The mother of a 6-year-old boy insists that her son take on a few household chores, for which he earns a small weekly allowance. Whenever he saves his allowance for two or three weeks, he has enough money to buy an inexpensive toy of his own choosing. In the process of being regularly paid for his work and saving his earnings, the boy acquires an increasing appreciation for the value of money.
- A college student from a small town is, for the first time, exposed to political viewpoints quite different from her own. After engaging in heated debates with classmates, she reflects on and gradually modifies her own political views.
- A toddler is overly affectionate with a neighborhood dog, and the dog responds by biting the toddler's hand. After this incident, the child cries and runs quickly to his mother every time he sees a dog.

As you can see, learning is the means through which we acquire not only skills and knowledge, but also values, attitudes, and emotional reactions.

For purposes of our discussions in this book, we'll define **learning** as a long-term change in mental representations or associations as a result of experience. Let's divide this definition into its three parts. First, learning is a *long-term change:* It isn't just a brief, transitory use of information—such as remembering a phone number long enough to call someone and then forgetting it—but it doesn't necessarily last forever. Second, learning involves *mental representations or associations* and so presumably has its basis in the brain. Third, learning is a change *as a result of experience,* rather than the result of physiological maturation, fatigue, use of alcohol or drugs, or onset of mental illness or dementia.

Sometimes learning is a very passive process: It happens simply by virtue of something happening *to* a learner. More often, however, it requires the learner to *do* something—something physical, something mental, or, ideally, something *both* physical and mental.

Determining When Learning Has Occurred

Many psychologists would agree with the definition of learning I've just presented. However, some would prefer that the focus be on changes in *behavior* rather than on changes in mental representations or associations (more on this point shortly). In fact, regardless of how we define learning, we know it has occurred only when we actually see it reflected in a person's behavior. For example, we might see a learner:

- Performing a completely new behavior—perhaps tying shoes correctly for the first time
- Changing the frequency of an existing behavior—perhaps more regularly cooperating with (rather than acting aggressively toward) classmates

- Changing the speed of an existing behavior—perhaps recalling certain subtraction facts more quickly than before
- Changing the intensity of an existing behavior—perhaps throwing increasingly outrageous temper tantrums as a way of obtaining desired objects
- Changing the complexity of an existing behavior—perhaps discussing a particular topic in greater depth and detail after receiving instruction about the topic
- Responding differently to a particular stimulus—perhaps crying and withdrawing at the sight of a dog after having previously been eager to interact with dogs

Throughout the book, we'll continue to see these and other approaches to assessing learning. Furthermore, we'll discover that the ways in which people's learning is assessed can either directly or indirectly have a significant impact on their *future* learning.

Types of Learning Research

Although psychologists may differ in their views of how best to define learning and determine when it has occurred, virtually all of them agree on one point: They can best understand the nature of learning by studying it objectively and systematically through research. The systematic study of behavior, including human and animal learning processes, has emerged only within the past century or so, making psychology a relative newcomer to scientific inquiry. But in a century's time, countless research studies have investigated how people and many other species learn.

When studying the nature of human learning, some psychologists conduct **basic research**: They investigate specific learning processes under tightly controlled conditions, often looking at people's responses to contrived learning experiences in a laboratory. Others conduct **applied research**: They investigate people's learning in more "real-world" tasks and settings—for instance, by looking at how children learn certain science concepts in middle school classrooms. The kinds of data collected vary from study to study as well. In some instances the data collected are **quantitative**, taking the form of measurements and other numbers. In other cases the data are **qualitative**, in that they're complex verbal or behavioral performances that a researcher must closely inspect and then judge for the presence or absence of specific contents or skills. All of these forms of research and data—basic and applied, quantitative and qualitative—have contributed immensely to our understanding of human learning, and thus I will draw heavily from all of them throughout the book.

Learning Principles and Theories

Consistent patterns in research findings have led psychologists to make generalizations about learning processes through the formulation of both principles and theories of learning. **Principles** of learning identify certain factors that influence learning and describe the specific effects these factors have. For example, consider this principle:

> A behavior that is followed by a satisfying state of affairs—a reward—is more likely to increase in frequency than a behavior not followed by a reward.

In this principle, a particular factor (a rewarding consequence) is identified as having a particular effect (an increase in the behavior's frequency). The principle can be observed in many situations, including the following:

- A pigeon is given a small pellet of food every time it turns its body in a complete circle. It begins rotating in circles quite frequently.
- Dolphins who are given fish for "speaking" in dolphinese quickly become quite chatty.
- A boy who completes a perfect spelling paper and is praised for it by a favorite teacher works diligently for future success in spelling assignments.
- A textbook author who receives compliments when she wears her hair in a French braid brushes her hair into a braid more often, especially when going to parties or other social events.

Principles are most useful when they can be applied to many different situations. The "reward" principle—many psychologists instead use the term *reinforcement*—is an example of such broad applicability: It applies to both humans and nonhuman animals and holds true for different types of learning and for a variety of rewards. When a principle such as this one is observed over and over again—when it stands the test of time—it is sometimes called a **law**.

Theories of learning provide explanations about the underlying mechanisms involved in learning. Whereas principles tell us *what* factors are important for learning, theories tell us *why* these factors are important. For example, consider this key idea in social cognitive theory (described in Chapter 5):

> People learn what they pay attention to. A reward increases learning when it makes people pay attention to the information to be learned.

Here we have a possible explanation of why a reward affects learning: It increases attention, which in turn brings about learning.

Principles of learning tend to be fairly stable over time: Researchers observe many of the same factors affecting learning over and over again. In contrast, theories of learning continue to change as new research methods are developed, new research is conducted, and new research findings come to light.

How Theories of Learning Have Evolved over Time

When psychologists first began to study learning in earnest in the late 1800s, the two dominant perspectives in psychology were *structuralism* (e.g., Wilhelm Wundt's work) and *functionalism* (e.g., John Dewey's writings). Although these two perspectives differed considerably in their underlying assumptions and topics of study, they shared a common weakness: They lacked a precise, carefully defined research methodology. The primary means of investigating learning and other psychological phenomena, especially for structuralists, was a method called *introspection:* People were asked to "look" inside their heads and describe what they were thinking.

In the early 1900s, some psychologists began to criticize the introspective approach for its subjectivity and lack of scientific rigor. Without more objective research methods, they argued, psychology as a discipline would never be a true science. They proposed that to study learning in an objective, scientific manner, theorists must focus on two things that can be observed and objectively measured: people's behaviors *(responses)* and the environmental events *(stimuli)* that precede and follow those responses. Since then, many psychologists have attempted to describe

and understand learning and behavior primarily through an analysis of stimulus–response relationships. Such psychologists are called *behaviorists,* and their theories of learning are collectively known as **behaviorism**.

The behaviorist perspective has contributed immensely to our understanding of how people learn and how instructional and therapeutic environments might help them learn and behave more effectively. Over the years, however, its limitations have become apparent. For example, early behaviorists believed that learning can occur only when learners actually behave in some way—perhaps when they make a response and experience the consequences of that response. But in the 1940s, some psychologists proposed that people can also learn a new behavior simply by watching and imitating what *other people* do (N. E. Miller & Dollard, 1941). This idea of *modeling* provided the impetus for an alternative perspective, **social learning theory**, that focused on how people learn from observing those around them.

Behaviorism and social learning theory developed largely in North America. Meanwhile, many early-twentieth-century researchers in Europe took an entirely different tack, presenting situations and tasks that might reveal the nature of people's internal mental processes. For instance, beginning in the 1920s, Swiss researcher Jean Piaget documented numerous ways in which children's reasoning processes change as they grow older, and Russian psychologist Lev Vygotsky conducted studies about how children's social and cultural environments can help them acquire more complex thinking skills. And in Germany, theorists known as **Gestalt** psychologists described a variety of intriguing findings related to such mental phenomena as human perception and problem solving.

Over time, as psychologists continued to explore the various forms that human learning might take, it became clear that a study of behavior alone couldn't give us a complete picture of learning—that we had to take human thought processes, or *cognition,* into account as well. A very different perspective emerged—one known as **cognitive psychology** or, more simply, **cognitivism**—with objective, scientific methods for studying a wide variety of mental phenomena (e.g., Neisser, 1967). Social learning theorists, too, gradually incorporated cognitive processes into their explanations of learning, resulting in a perspective now more often referred to as **social cognitive theory**.

But even with a focus on cognition as well as behavior, we can't completely pinpoint the distinct advantage that we humans have over nonhuman animal species. Many nonhuman animals are *thinking* creatures. For example, several species (e.g., gorillas, chimpanzees, dolphins, elephants—remember Somjai?—and crows) can recognize themselves in a mirror, suggesting that they have a mental image of what they look like (S. T. Parker, Mitchell, & Boccia, 1994; Plotnik, de Waal, & Reiss, 2006; Prior, Schwarz, & Güntürkün, 2008). Furthermore, some animal species can create and use simple tools to get things they want, and they can mentally plan ahead to solve a problem or ensure their future well-being (Emery & Clayton, 2004; Köhler, 1925; Plotnik, Lair, Suphachoksahakun, & de Waal, 2011). Crows, for instance, can craft rudimentary tools to get hard-to-reach food, and they plan ahead by stashing away what they don't immediately eat in locations that they can later remember.

So how can we explain the human advantage in thinking and learning? For one thing, our physical "thinking" equipment—especially the upper part of the brain known as the cortex—is more complex than is true for other species. But in addition, thanks in part to our incredibly flexible language skills, we communicate and collaborate with one another to a much greater extent than other species do, and through the elaborate cultures we've created for ourselves and our communities, we pass along our accumulated knowledge to successive generations

(Tomasello & Herrmann, 2010). Furthermore, our social and cultural environments provide many physical and social support systems (e.g., technology, schools) that can boost our ability to tackle new challenges and problems. Building on Russian psychologist Lev Vygotsky's early ideas, in the past three or four decades some psychologists have developed theories about the critical roles that social interaction and cultural legacies play in human learning and cognitive development. Many labels have been applied to such interaction-and-culture-based perspectives. The most widely used label is **sociocultural theory**, but more broadly we can think of them as **contextual theories**.

Meanwhile, recent technological innovations in the fields of medicine and neurology now enable us to "look inside" the brain—to study its structures and functions in increasing detail (more on such technologies in Chapter 2). Some neurologists, cognitive psychologists, and scientists from other disciplines have teamed up to discover how the brain influences people's behavior and learning, and, conversely, how people's behavior and learning experiences can influence brain development. This rapidly expanding field is known as **cognitive neuroscience** and has already made noteworthy contributions to our understandings of the complexities of human learning.

Figure 1.2 provides a graphic depiction of how various theories of learning have evolved over time. Be careful, however, that you don't interpret the boxes in the figure as depicting mutually exclusive entities. In contemporary psychology, many theorists draw from two or more theoretical perspectives to better capture the complex nature of human thinking and learning (notice the two-way cross-communication arrows between the "Cognitive Psychology," "Social Cognitive Theory," and "Sociocultural Theory and Other Contextual Theories" boxes). As we consider the many aspects of human learning in the chapters ahead, we, too, will occasionally find it helpful to draw from two or more perspectives simultaneously.

Advantages of Theories

Certainly the changeable nature of theories can be frustrating, in that we can never be confident that we have the ultimate truth—the real scoop—on how people learn. Yet it's precisely the dynamic nature of learning theories that enables us to gain increasingly accurate understandings of a very complex, multifaceted phenomenon.

Theories have several advantages over principles. First, they allow us to summarize the results of many, many research studies and integrate numerous principles of learning. In that sense, theories are often quite concise (psychologists use the term *parsimonious*).

Second, theories provide starting points for conducting new research; they suggest research questions worthy of study. If we theorize that rewards bring about learning because they increase a person's attention to whatever needs to be learned, we can make the following prediction:

> When a particular situation or task draws an individual's attention to the information to be learned, learning occurs even in the absence of a reward.

In fact, this prediction has frequently been supported by research (e.g., Cermak & Craik, 1979; Faust & Anderson, 1967; T. S. Hyde & Jenkins, 1969).

Third, theories help us make sense of and explain research findings. Research conducted outside the context of a particular theoretical perspective can yield results that are trivial and nongeneralizable. Interpreted from a theoretical perspective, however, those same results can be quite meaningful. For example, consider an experiment by Seligman and Maier (1967). In this

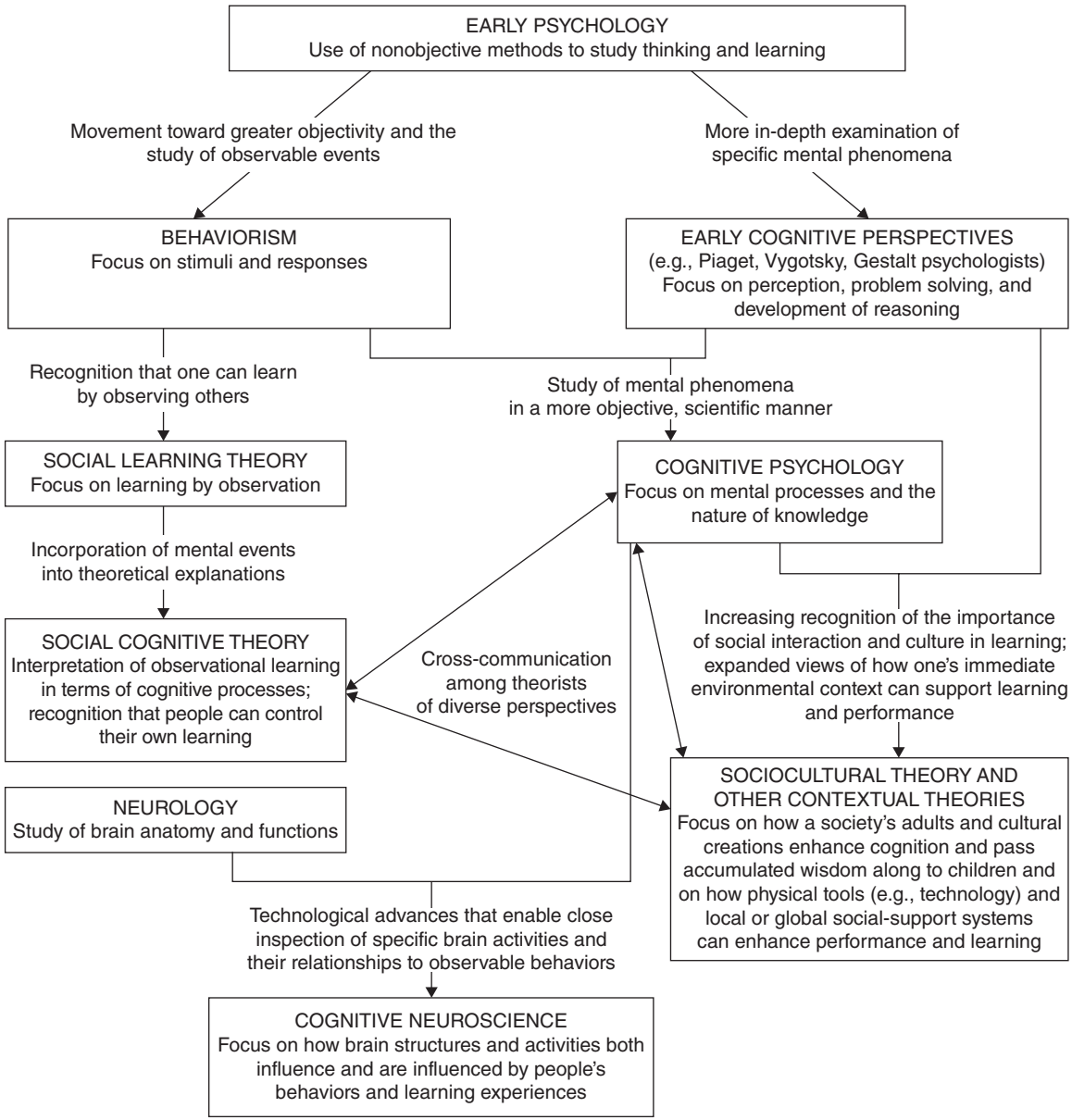

Figure 1.2
Evolution of learning theories over time.

classic study, dogs were placed in individual cages and given a number of painful and unpredictable shocks. Some dogs were able to escape the shocks by pressing a panel in the cage, whereas others were unable to escape. The following day, the dogs were placed in different cages, and again shocks were administered. This time, however, each shock was preceded by a signal (a tone) that the shock was coming, and the dogs could avoid the shocks by jumping over a barrier as soon

as they heard the tone. The dogs that had been able to escape the shocks on the preceding day learned to avoid the shocks altogether in this new situation, but the dogs that had been unable to escape previously did *not* learn to avoid the shocks.[1] On the surface, this experiment might not seem especially relevant to human learning. Yet Seligman and his colleagues used this and other experiments to develop their theory of *learned helplessness:* People who learn that they have no control over unpleasant or painful events in one situation are unlikely, in later situations, to try to escape or avoid aversive events even when it's possible for them to do so. In Chapter 15, we'll look at learned helplessness more closely and incorporate it into a general theoretical framework known as *attribution theory.*

Theories have a fourth advantage as well: By giving us ideas about the mechanisms that underlie human learning and performance, they can ultimately help us design instructional and therapeutic strategies and environments that facilitate human learning and development to the greatest possible degree. For example, consider the teacher who is familiar with the theory that attention is an essential ingredient in the learning process. That teacher might identify and use a variety of approaches—perhaps providing interesting reading materials and presenting intriguing problems—that are likely to increase students' attention to academic subject matter. In contrast, consider the teacher who is familiar only with the principle that rewarded behaviors are learned. That teacher might use certain rewards—perhaps small toys or trinkets—that are counterproductive because they draw students' attention to objects that are irrelevant to classroom learning tasks.

Potential Drawbacks of Theories

Despite their advantages, theories also have two potential drawbacks. First, no single theory explains everything researchers have discovered about learning. Current theories of learning tend to focus only on certain aspects of learning. For instance, behaviorist theories limit themselves primarily to learning that involves discrete, observable responses; cognitive theories tend to focus on how individual learners interpret, integrate, and remember information; and sociocultural theories deal largely with how interpersonal processes and cultural creations enter into the picture. Theorists who adhere to a particular perspective are apt to either ignore or discredit phenomena that don't fit comfortably within it.

Second, theories affect the new information that's published, thereby biasing the knowledge we have about learning. For example, imagine that several researchers propose a particular theory of learning and conduct a research study to support their idea. They obtain results that are opposite to what they expected and thus cast doubt on their theory. If these researchers are fully committed to demonstrating that their theory is correct, they're unlikely to publish results that would indicate otherwise! In this way, theories may occasionally impede progress toward truly accurate understandings of learning.

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[1]If this "shocking" treatment of dogs upsets you—as it does me—be assured that researchers can no longer do whatever they want to participants in their studies. They must now adhere to strict ethical guidelines regarding treatment of both humans and nonhuman animals in their research. Universities and other research institutions oversee research projects through Institutional Review Boards (IRBs, for research with humans) and Institutional Animal Care and Use Committees (IACUCs, for research with nonhuman animal species).

A Perspective on Theories and Principles

Most psychologists tend to align themselves with a particular theoretical perspective, and I, whose graduate training and research program have been rooted in cognitive traditions, am no exception. Yet I firmly believe that diverse theories all offer unique insights and thus have important things to say about human learning. I hope that as you read this book, you'll take an equally open-minded approach. Keep in mind, too, that as many more research studies are conducted in the decades ahead, theories of learning will continue to be revised to account for the new evidence that emerges, to the point where I must revise this book in significant ways every three or four years. In this sense, no single theory can be considered fact. It's probably more helpful to think of theories in terms of their *usefulness* than in terms of their *this-is-the-ultimate-truth* correctness.

At the same time, you might think of general principles as reflecting relatively enduring conclusions about cause-and-effect relationships in the learning process. The *reward* principle was introduced by Edward Thorndike in 1898 and has remained with us in one form or another ever since. Thorndike's original theory of *why* reward affects learning, however, has largely been replaced by other explanations.

Principles and theories alike help us predict the conditions under which successful learning is most likely to occur. To the extent that they're useful in this way, we're better off with them—imperfect and tentative as some of them may be—than without them.

Applying Knowledge about Learning to Instructional Practices

A great deal of learning takes place in classroom contexts, and most of it is beneficial. For example, it's in the classroom that most children learn how to read and how to subtract one number from another. Unfortunately, children may also learn things at school that *aren't* in their best interests over the long run. For instance, although they may learn to read, they may also learn that the "best" way to remember what they read is to memorize it, word for word, without necessarily trying to understand it. And although they may learn their subtraction facts, they may also learn that mathematics is a boring or frustrating endeavor.

With human beings so dependent on their environment to acquire the knowledge and skills they'll need in order to become productive members of society, the learning that takes place in educational institutions—elementary schools, high schools, universities, and elsewhere—cannot be left to chance. To maximize productive student learning, teachers must understand the factors that influence learning (principles) and the processes that underlie it (theories). They must also draw on research findings regarding the effectiveness of various instructional practices.

Because varying theoretical orientations approach human learning in distinctly different ways, they can also prescribe somewhat different strategies for enhancing people's learning and achievement in instructional settings. I urge you not only to be open-minded about the various theories you'll encounter in the book but also to take an eclectic attitude toward the diverse instructional strategies I describe, resisting the temptation to choose one approach over others as being the "right" one. All of the strategies included in the book are applicable in certain situations, depending on the environmental conditions at hand, the specific subject matter being learned, and the goals of instruction.

Overview of the Book

In our exploration of human learning, a good starting point is its physiological underpinnings, which we'll examine in Chapter 2. There we'll look at components of the human nervous system and consider where and how learning probably occurs in the brain. We'll also consider what brain research tells us—as well as what it *doesn't* tell us—about thinking, learning, and instruction in classroom settings.

In Part II of the book, we'll explore principles and theories of learning from the behaviorist perspective, focusing on relationships between environmental events (stimuli) and the behaviors (responses) that people acquire as a result of those events. We'll begin by identifying a few general assumptions that underlie behaviorist approaches and examining how learning can result from either consistent stimulus–stimulus pairings or response–consequence contingencies in one's environment (Chapter 3). We'll then see how behaviorist principles can be effectively applied in educational and therapeutic settings (Chapter 4).

In Part III (Chapter 5), social cognitive theory will help us make the transition from behaviorism to cognitivism. As you'll discover, social cognitive theory offers a nice blend of behaviorist and cognitive ideas regarding how and what people learn by observing others and also how, with the acquisition of self-regulation skills, most people increasingly gain control of their own behavior.

In Part IV, we'll turn to theories of learning that are almost entirely cognitive in nature. We'll look at several cognitive perspectives, both old and new, that have contributed to our understanding of how people think and learn (Chapter 6). We'll then zero in on some of the mental processes involved in learning and memory (Chapter 7 and Chapter 8) and the nature of knowledge that such processes yield (Chapter 9).

In Part V, we'll examine learning and cognition from developmental, sociocultural, and other contextual perspectives. There we'll look at the work of two groundbreaking developmental theorists—Swiss researcher Jean Piaget (Chapter 10) and Russian psychologist Lev Vygotsky (Chapter 11)—as well as at the work of contemporary researchers who have built on their ideas.

As we proceed to Part VI, we'll examine more complex aspects of human learning and cognition. Specifically, we'll look at how well people understand and regulate their own thinking processes—a phenomenon known as *metacognition* (Chapter 12)—and how effectively people can apply what they've learned in one situation to new tasks and problems (Chapter 13).

Finally, in Part VII, we'll consider the role that motivation plays in learning. We'll look at motivation's effects on learning and behavior, identify some of the basic needs that human beings have, and examine how emotion (*affect*) is closely intertwined with both motivation and learning (Chapter 14). We'll also identify numerous cognitive factors that enter into and shape motivational processes (Chapter 15).

Throughout the book, we'll frequently identify educational implications of the principles and theories we are studying. I hope that once you've finished the final chapter, you'll be convinced, as I am, that psychology has a great deal to offer about how we can enhance teaching and learning both inside and outside the classroom.

Summary

Learning allows human beings a greater degree of flexibility and adaptability than is true for any other species. A definition that incorporates many psychologists' ideas about the nature of *learning* is this one: *a long-term change in mental representations or associations as a result of experience*. However, some psychologists prefer to define learning as a change in behavior rather than a mental change, and, in fact, we can be confident that learning has occurred only when we *do* see a behavior change of some kind.

An accurate, dependable understanding of the nature of human learning can emerge only by studying learning through objective, systematic research. Consistent patterns in research findings have led psychologists to formulate both *principles* (descriptions of what factors affect learning) and *theories* (explanations of why those factors have the effects they do) about learning. Principles tend to be fairly stable over time, whereas theories continue to evolve as new research findings are reported. Effective teachers and other practitioners draw on a wide variety of research findings, principles, and theoretical perspectives as they design and implement instructional practices and interventions.

CHAPTER 2

LEARNING AND THE BRAIN

LEARNING OUTCOMES

2.1. Describe the nature and functions of three major building blocks of the nervous system: neurons, synapses, and glial cells.

2.2. Distinguish among various key structures in the human brain, and explain why, in most circumstances, it makes little or no sense to talk about teaching to learners' "left brains" or "right brains."

2.3. Describe key phenomena in brain development, including synaptogenesis, differentiation, synaptic pruning, myelination, plasticity, and sensitive periods; also describe several ways in which people may be "prewired" to know or learn certain things from their physical or social environments.

2.4. Describe four neurological phenomena that probably play roles in learning and memory.

2.5. Identify educational practices that are consistent with what we currently know about the brain's health and development.

Someone in my family has a broken brain; to protect his privacy, I'll simply call him Loved One. As a child, Loved One was in most respects quite normal: He did well in school, spent after-school hours playing typical "boy" games with his friends, and often traveled to places near and far with his parents and siblings. People who knew him described him as smart, sweet, and sensitive. But even then, there were, perhaps, little cracks in his brain. For one thing, he had trouble delaying gratification: He always wanted things now, now, now. And he made many poor choices in his daily decision making—for example, leaving a pet turtle unattended on his bed (leading to a fatal fall) and smashing unwanted toys on the back patio using a hammer that left huge smash marks on the patio stones.

When Loved One was 17 years old, something went seriously wrong. Despite curfews and significant consequences for ignoring them, he would stay out until the wee hours of the morning;

sometimes he didn't return home until the following afternoon. He became hostile and defiant, and his parents found him impossible to reason with. He often refused to get out of bed to go to school. His grades plummeted, and by December of his senior year it was clear that he wouldn't have enough credits to graduate with his high school class. In January, his out-of-control behavior landed him in a juvenile detention center. While awaiting trial, he became increasingly lethargic until eventually he could barely move: He wouldn't eat and didn't seem able to walk or talk. When, on the day of his trial, he was brought into the courtroom in a wheelchair—awake but unresponsive—the judge remanded him to the state mental hospital.

Loved One has been diagnosed as having *bipolar disorder,* a condition characterized by periods of elation and intense activity (mania) followed by periods of deep sadness and lethargy (depression). Particularly during the manic periods, Loved One has *psychosis*: His thinking is impaired to the point that he can't function normally. He seems unable to reason, make appropriate decisions, or control his impulses. Furthermore, he often has auditory hallucinations, hearing voices that aren't there. Such psychotic symptoms are often seen in another serious mental illness, *schizophrenia,* as well.

The right medication can do wonders for Loved One: It calms him down, clears his thoughts, gives him back his impulse control, and helps him appropriately interpret and respond to events in his daily life. Medication has enabled Loved One to acquire his graduate equivalency diploma (GED) and earn Bs in occasional classes at a local community college. But like many people with mental illness, Loved One doesn't always stay on his medication. When he doesn't, his brain goes haywire and his behaviors land him in jail and, if he's lucky, back in the hospital. Loved One typically remembers very little of what he does or what happens to him when he's psychotic. Maybe that's just as well.

The human brain is an incredibly complex mechanism, and researchers have a long way to go in understanding how it works and why it doesn't always work as well as it should. Yet they've made considerable progress in the past few decades, and their knowledge about brain anatomy and physiology grows by leaps and bounds every year.

In this chapter we'll look at the biological underpinnings of thinking and learning. We'll begin by putting the basic building blocks of the human nervous system under the microscope. We'll then examine various parts of the brain and the functions that each appears to have. Later, we'll trace the brain's development over time (at that point we'll speculate about why Loved One's brain broke down when it did) and look at theorists' beliefs about the physiological basis of learning. Finally, we'll consider what educational implications we can draw—as well as what implications we *cannot* draw—from current knowledge and research about the brain. As we address these topics, we'll discredit some common myths about the brain that appear all too frequently in educational literature.

Basic Building Blocks of the Human Nervous System

The human nervous system has two main components. The **central nervous system**, comprising the brain and spinal cord, is the coordination center: It connects what we sense (e.g., what we see, hear, smell, taste, and feel) with what we do (e.g., how we move our arms and legs). The **peripheral nervous system** is the messenger system: It carries information from *receptor cells*—cells specialized to detect particular kinds of stimulation from the environment (e.g., light,

sound, chemicals, heat, pressure)—to the central nervous system, and it carries directions back to various body parts (muscles, organs, etc.) about how to respond to that stimulation.

Nerve cells, or **neurons**, provide the means through which the nervous system transmits and coordinates information. Curiously, however, neurons don't directly touch one another; they send chemical messages to their neighbors across tiny spaces known as **synapses**. Furthermore, neurons rely on other cells, known as **glial cells**, for structure and support. We'll now look at the nature of each of these key elements of the nervous system.

Neurons

Neurons in the human body play one of three roles. **Sensory neurons** carry incoming information from receptor cells. They convey this information to **interneurons**, which integrate and interpret input from multiple locations. The resulting "decisions" are transmitted to **motor neurons**, which send messages about how to behave and respond to appropriate parts of the body.[1] As you might guess, sensory neurons and motor neurons are located in the peripheral nervous system. The vast majority of interneurons—about *one hundred billion* of them—are found in the central nervous system, especially in the brain (C. S. Goodman & Tessier-Lavigne, 1997; D. J. Siegel, 2012). Because neurons in the brain are brownish-grayish in color, they are sometimes collectively known as *gray matter.*

Neurons vary in shape and size, but all of them have several features in common (see Figure 2.1). First, like all cells, they have a cell body, or **soma**, that contains the cell's nucleus and is responsible for the cell's general health and well-being. In addition, they have a number of branchlike structures, known as **dendrites**, that receive messages from other neurons. They also have an **axon**, a long, armlike structure that transmits information to additional neurons (occasionally, a neuron has more than one axon). The end of the axon may branch out many times, and the ends of its tiny branches have **terminal buttons**, which contain certain chemical substances (more about these substances shortly). For some (but not all) neurons, much of the axon is covered with a white, fatty substance known as a **myelin sheath**.

When a neuron's dendrites are stimulated by other cells (either receptor cells or other neurons), the dendrites become electrically charged. Sometimes the charges are so small that the neuron essentially "ignores" them. But when the charges reach a certain level (known as the **threshold of excitation**), the neuron fires, sending an electrical impulse along its axon to the terminal buttons. If the axon has a myelin sheath, the impulse travels very quickly: The electrical message jumps from one gap in the myelin to the next, almost as if it were playing leapfrog. If the axon doesn't have a myelin sheath, the impulse travels more slowly.

Synapses

The branching ends of a neuron's axon reach out to—but don't quite touch—the dendrites (in some cases, the somas) of other neurons. Whereas transmission of information within a neuron is electrical, transmission of information from one neuron to another is chemical. When an

[1]You may sometimes see the terms *receptor neurons, adjuster neurons,* and *effector neurons* used for sensory neurons, interneurons, and motor neurons, respectively.

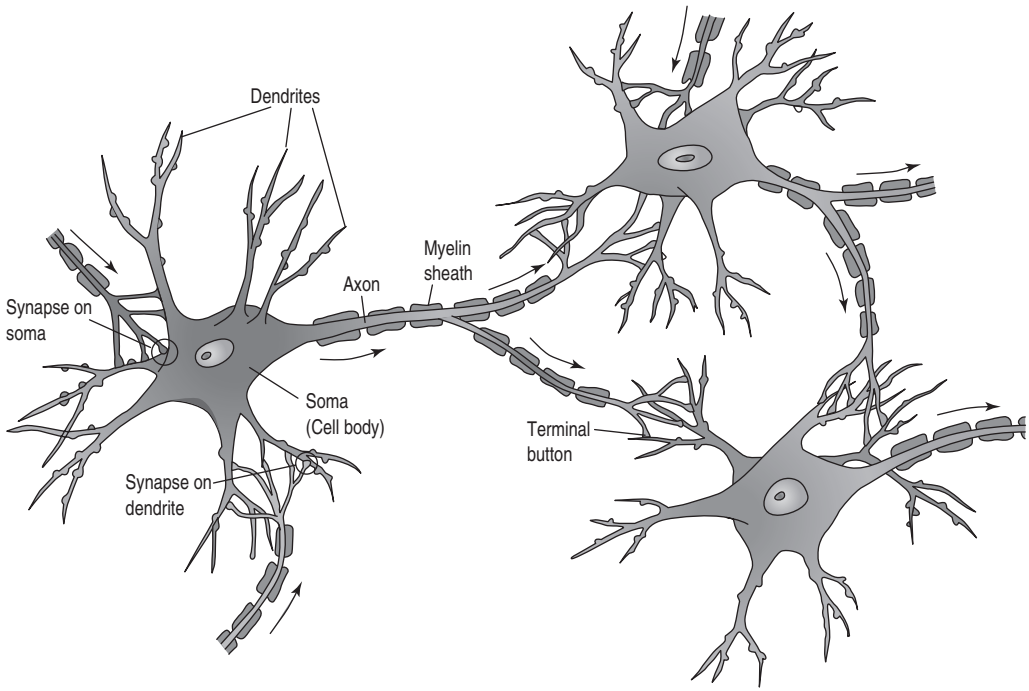


Figure 2.1
The nature of neurons and their interconnections.

electrical impulse moves down a neuron's axon, it signals the terminal buttons to release chemicals known as **neurotransmitters**. These chemicals travel across the synapses and stimulate the dendrites or somas of neighboring neurons.

Different neurons specialize in different kinds of neurotransmitters. Perhaps in your readings about health, fitness, or related topics, you've seen references to dopamine, epinephrine, norepinephrine, serotonin, amino acids, or peptides. All of these are neurotransmitters, and each of them may play a unique role in the nervous system. For instance, dopamine is a key neurotransmitter in the frontal lobes of the cortex, which, as you'll discover shortly, are actively involved in consciousness, planning, and the inhibition of irrelevant behaviors and ideas (Goldman-Rakic, 1992; M. I. Posner & Rothbart, 2007). Some evidence indicates that schizophrenia and other serious psychiatric disorders are sometimes the result of abnormal dopamine levels (Barch, 2003; Clarke, Dalley, Crofts, Robbins, & Roberts, 2004; E. Walker, Shapiro, Esterberg, & Trotman, 2010). (Recall Loved One's difficulties with decision making and impulse control.)

Any single neuron may have synaptic connections with hundreds or thousands of other neurons (C. S. Goodman & Tessier-Lavigne, 1997; Lichtman, 2001; Mareschal et al., 2007). Some neurotransmitters increase the level of electrical activity in the neurons they stimulate, whereas others inhibit (i.e., decrease) the level of electrical activity. Whether a particular neuron fires, then, is the result of how much it is "encouraged" and "discouraged" by its many neighbors.

Glial Cells

Only about 10% of the cells in the brain are neurons. Accompanying neurons are perhaps one to five trillion glial cells (also known as *neuroglia*), which are whitish in color and thus collectively known as *white matter.* All of that seemingly empty space between the neurons depicted in Figure 2.1 isn't empty at all; it's chock full of glial cells of various shapes and sizes.

Glial cells appear to serve a variety of specialized functions (Koob, 2009; Oberheim et al., 2009). Some are "nutritionists" that control blood flow to neurons, "doctors" that tend to infections and injuries, or "clean-up crew" that clear away unwanted garbage in the brain. Others provide the myelin sheath of which I just spoke—the axon coating that enhances the efficiency of many neurons. And a great many of them appear to play a direct and critical role in learning and memory, as you'll discover later in the chapter.

In the human brain, these basic building blocks—neurons, synapses, and glial cells—make it possible for us to survive (e.g., by breathing and sleeping), to identify the stimuli we encounter (e.g., recognizing a piece of fruit or a good friend), to feel emotion (e.g., becoming afraid when we encounter danger), and to engage in the many conscious thought processes (e.g., reading, writing, solving mathematical problems) that are distinctly human.

Brain Structures and Functions

In some instances, sensory neurons connect directly with motor neurons in the spinal cord, enabling an automatic response, or **reflex**, that involves no thought whatsoever. For example, if you touch something that's really hot, sensory neurons traveling from your fingertips up through your arm and into your spinal cord tell the motor neurons that go back to your arm and hand muscles to quickly pull your fingers away. Your brain certainly perceives the heat you've encountered, but not until after your spinal cord has already taken charge of the situation and removed you from danger.

For the most part, however, information from the outside world travels to the brain, which then decides whether and how to respond. Given the sheer number of cells in the brain—several trillion of them altogether—along with their microscopic size and countless interconnections, researchers have faced quite a challenge in figuring out how the brain works and what parts serve what functions. Yet they've made considerable progress, as you'll see in the next few pages.

Methods in Brain Research

In their work, neuroscientists have had several methodologies at their disposal:

- *Studies with animals.* Some researchers take liberties with animals (e.g., laboratory rats) that they would never take with human beings. For instance, they may remove a certain part of an animal's brain, insert a tiny needle into a certain location and electrically stimulate it, increase the levels of certain hormones, or inject chemicals that block certain neurotransmitters. They then observe changes in the animal's behavior and assume that these changes reflect the functions that particular brain structures, hormones, or neurotransmitters serve.[2]

[2]As previously noted in a footnote in Chapter 1, any research of this nature must be approved by an Institutional Animal Care and Use Committee (IACUC), which carefully weighs the pros and cons of inflicting such harm on animals.

- *Postmortem studies.* Some people may, while living, agree to donate their brains for scientific study after they have died. Others may donate the brains of recently deceased family members for whom they are the legal next-of-kin. By examining the brains of children and adults of varying ages, researchers can determine typical human brain structures and how brain anatomy may change with development.
- *Case studies of people with brain injuries and other pathological conditions.* Researchers take detailed notes about what people with brain injuries or certain pathologies (e.g., schizophrenia, dyslexia) can and cannot do during their lifetimes. Then, after death, they examine the individuals' brains to identify areas of abnormality (e.g., specific sites of an injury, abnormal brain structures). If the absence of certain abilities in life is consistently associated with certain brain abnormalities, researchers reasonably conclude that the affected brain areas play key roles in the missing abilities.
- *Electrical recording.* Researchers place electrodes at strategic locations on a person's scalp and record patterns of electrical activity in the brain. The resulting record, known as an *electroencephalograph (EEG),* tends to show different patterns of brain waves for different activities (e.g., for sleep versus wakefulness). Often researchers collect EEG data while people perform specific tasks, yielding *event-related potentials (ERPs)* that provide clues regarding the nature of brain activity during those tasks.
- *Neuroimaging.* Using a variety of recent technological advances, researchers take pictures of blood flow or metabolism rates in various parts of the brain as people do certain things. Presumably, areas of greater blood flow or metabolic action reflect areas of the brain that contribute in significant ways to a particular activity. Common techniques are positron emission tomography (PET), single-photon emission computed tomography (SPECT), computerized axial tomography (CAT), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG). And as neuroscientists have increasingly recognized that two or more parts of the brain often interact in even the simplest of activities, they have also begun to use functional connectivity MRI (fcMRI), a technique that enables them to determine what brain regions consistently work *together* in one situation or another.

None of these methods is perfect. Laboratory rats don't have many of the sophisticated cognitive abilities that humans do. Postmortem studies of normal human brains reveal an overall decline in the number of synapses in middle childhood and adolescence (more about this point later), but they don't tell us to what degree children also form *new* synapses as they grow. Brain injuries may simultaneously affect multiple regions of the brain. Electroencephalographs don't tell us precisely where particular thought processes are occurring. And neuroimaging involves expensive diagnostic equipment with only limited availability for basic research. Nevertheless, taken together, research using these techniques is helping scientists identify and assemble some of the pieces of the puzzle about how the human brain works and develops.

Parts of the Brain

The human brain includes a number of distinct structures that have somewhat different functions; structures especially pertinent to our discussion in this chapter are shown in Figure 2.2. Together these structures comprise three major components of the brain, which have emerged at different points along our evolutionary journey. The **hindbrain**, located in the lower part of

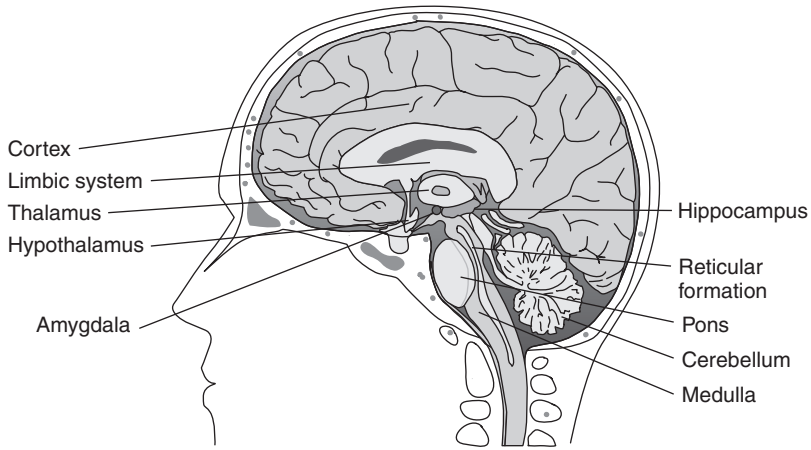


Figure 2.2
Key parts of the brain: The figure shows a vertical slice near the middle of the brain; hence, the right and left sides of the cortex are missing.

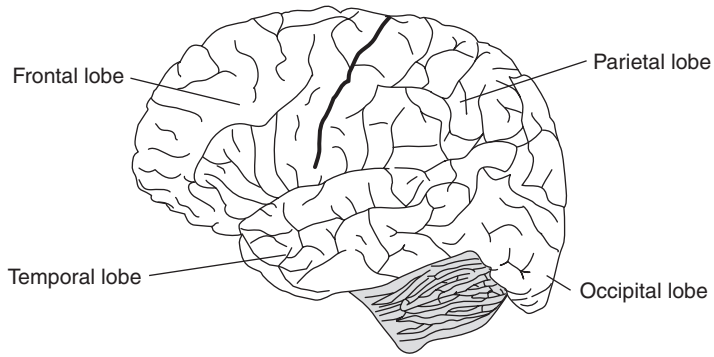
the brain where the spinal cord enters the skull, appeared first in evolution and appears first in prenatal development. Made up of several smaller structures (e.g., the medulla, pons, and cerebellum), the hindbrain is involved in many basic physiological processes that keep us alive (breathing, swallowing, sleeping, regulating heartbeat, etc.). The cerebellum, at the lower rear of the brain, is actively involved in balance and complex motor behaviors (e.g., walking, riding a bicycle, playing tennis).

Next in both evolutionary and prenatal development is the **midbrain**, which plays supporting roles in vision and hearing (e.g., helping to control and coordinate eye movements). Probably the most noteworthy part of the midbrain is the **reticular formation** (also called the *reticular activating system,* or RAS), which extends into the hindbrain as well. The reticular formation is a key player in attention and consciousness; for example, it alerts us to potentially important stimuli that the body's receptors are encountering.

Last to come along is the **forebrain**, located in the front and upper portions of the brain. The forebrain is where most complex activities take place in primate species, especially human beings. Resting on top, like a thick, lumpy toupee, is the **cerebral cortex**—often simply called the **cortex**—which is divided into two halves (**hemispheres**) that, on the surface, appear to be mirror images of each other. Neurologists conceptualize the hemispheres of the cortex as having four major parts, or *lobes,* named after the parts of the skull that cover them (see Figure 2.3):

- *Frontal lobes.* Located at the front and top of the cortex, the frontal lobes are where much of our conscious thinking seems to occur. The frontal lobes are largely responsible for a broad range of complex human activities, including language, sustained attention, planning, reasoning, problem solving, self-regulation, deliberately controlled body movements, and interpretation of other people's behaviors. In addition, the frontal lobes are instrumental in inhibiting irrelevant and inappropriate thoughts and actions. The very front of the frontal lobes—a section known as the **prefrontal cortex**, located immediately behind the forehead—is especially important in conscious, controlled thinking. (I suspect that much of Loved One's illness involves malfunctioning of his prefrontal cortex.)
- *Parietal lobes.* Located in the upper back portion of the cortex, the parietal lobes receive and interpret somatosensory information—that is, information about temperature,

Figure 2.3
Side view of the cortex.



pressure, texture, and pain. These lobes are also actively involved in paying attention, processing word sounds, and thinking about the spatial characteristics of objects and events.

- *Occipital lobes.* Located at the very back of the brain, the occipital lobes have major responsibility for interpreting and remembering visual information.
- *Temporal lobes.* At the sides, behind the ears, are the temporal lobes, which interpret and remember complex auditory information (e.g., speech, music). The temporal lobes also appear to be important in memory for information over the long run (something we'll later call *long-term memory*), especially for general concepts and knowledge about the world.

In some cases, researchers have pinned down fairly specific regions of the cortex in which certain kinds of processing seem to occur. But many areas of the cortex aren't so clearly specialized. These areas, known as *association areas,* appear to integrate information from various parts of the cortex, as well as from other parts of the brain, and thus are essential for complex thinking and behavior.

Inside and below the cortex are several other parts of the forebrain. Following are some especially noteworthy ones:

- *Limbic system.* Closely connected with the cortex is a cluster of structures, collectively known as the limbic system, that are essential to learning, memory, emotion, and motivation. A small structure known as the *hippocampus* (Greek for "seahorse," which it loosely resembles) is intimately involved in attention and learning, especially for things that we consciously (rather than unconsciously) learn and remember. Another structure, the *amygdala,* figures prominently in emotions (especially unpleasant ones such as fear, stress, anger, and depression) and in automatic emotional reactions (e.g., aggression). Furthermore, the amygdala enables us to associate particular emotions with particular stimuli or memories. Although Figure 2.2 shows only one hippocampus and one amygdala, we have two of each, which are located on opposite sides of the brain.
- *Thalamus.* The thalamus, located in the very middle of the brain, serves as a "switchboard operator" that receives incoming information from various sensory neurons and sends it on to appropriate areas of the cortex. It also plays a role in arousal, attention, and fear.
- *Hypothalamus.* Located beneath the thalamus, the hypothalamus regulates many activities related to survival, such as breathing, regulating body temperature, feeling hunger and thirst, mating, fighting, and fleeing from harm.

The Left and Right Hemispheres

To some degree, the left and right hemispheres have different specialties. Curiously, the left hemisphere is largely responsible for controlling the right side of the body, and vice versa. For most people, the left hemisphere seems to be in charge of language, with two particular areas being major players in speech production and language comprehension (these are known as Broca's area and Wernicke's area, respectively). Reading and mathematical calculation skills also seem to be heavily dependent on the left hemisphere. In contrast, the right hemisphere is more dominant in visual and spatial processing, such as locating objects in space, perceiving shapes, estimating and comparing quantities, drawing and painting, mentally manipulating visual images, recognizing faces and facial expressions, and interpreting gestures. In general, the left side is more likely to handle details, whereas the right side is better suited for looking at and synthesizing an overall whole (Booth, 2007; Byrnes, 2001; R. Ornstein, 1997; D. J. Siegel, 2012; M. S. C. Thomas & Johnson, 2008).

Yet contrary to a popular myth, people rarely, if ever, think exclusively in one hemisphere; there's no such thing as "left-brain" or "right-brain" thinking. The two hemispheres are joined together by a large collection of neurons (the *corpus callosum*) that enables constant communication back and forth, and so the hemispheres typically collaborate in day-to-day tasks. Let's take language comprehension as an example. The left hemisphere handles such basics as syntax and word meanings, but it seems to interpret what it hears and reads quite literally. The right hemisphere is better able to consider multiple meanings and take context into account; hence, it's more likely to detect sarcasm, irony, metaphors, and puns (Beeman & Chiarello, 1998; Goel et al., 2007; R. Ornstein, 1997). Without your right hemisphere, you'd find no humor in the following joke, which I've seen in several variations on the Internet:

> A woman gives birth to identical twin boys. Because she and her husband have very little money, they regretfully give up their babies for adoption. A Spanish couple adopts one baby and names him Juan. An Egyptian couple adopts the other and calls him Amal. Several years later the Spanish couple sends the woman a picture of Juan.
>
> "Ah," the woman says wistfully, "I wish I had a picture of Amal as well."
>
> "But honey," her husband responds, "they're identical twins. If you've seen Juan, you've seen Amal."

The joke works only if you recognize that it's a twist of the common expression "If you've seen one, you've seen them all"—a connection you're most likely to make in your right hemisphere.

About 80% of human beings have left and right hemispheres that are specialized in the ways I've just described. For instance, the left hemisphere is the primary language hemisphere for more than 90% of right-handed individuals but for only about 60% of left-handed folks. People differ, too, in how hemispherically lopsided their thinking is: Whereas some often rely predominantly on one hemisphere or the other (depending on the circumstances), others regularly think in a fairly balanced, two-sided manner (R. Ornstein, 1997; D. J. Siegel, 2012).

As you can see, then, functions of some areas of the brain (especially in the cortex) are hardly set in stone. Occasionally, one area may take over a function that another area typically serves. For example, if, before age 1, children sustain damage to the left hemisphere or have part of their left hemisphere surgically removed (perhaps to address severe epileptic seizures), the right hemisphere steps in and enables the children to acquire normal language capabilities. Congenitally blind children may enhance their sense of hearing by recruiting areas that are usually devoted

to vision. Furthermore, different areas of the cortex may take on different roles as a result of the specific stimuli and tasks being encountered while each cortical area is actively changing and maturing (Beeman & Chiarello, 1998; Bryck & Fisher, 2012; Doidge, 2007; D. L. Mills & Sheehan, 2007; R. Ornstein, 1997; Stiles & Thal, 1993).

Interconnectedness of Brain Structures

As you may have noticed in our earlier discussion of various brain structures, many aspects of daily functioning—for instance, attention, learning, memory, and motor skills—are handled in multiple places. And as you've just discovered, the two hemispheres usually work together to understand and respond to the world. Remember, too, that any single neuron is apt to have hundreds of synapses (or more) with other neurons. As information travels through the brain, messages go every which way—not only from "lower down" in the processing system (i.e., at points where sensory information first reaches the brain) to "higher up" (i.e., at points where information is synthesized and interpreted or where behaviors are chosen and controlled) but also in the opposite direction and across areas that handle very different sensory modalities and motor functions. In essence, learning or thinking about virtually anything—even a single word—tends to be *distributed* across many parts of the brain (Chein & Schneider, 2012; Gonsalves & Cohen, 2010; Pereira, Detre, & Botvinick, 2011).

How does such a complex, interconnected mechanism—the human brain—come into being? Mother Nature's handiwork is quite a marvel. We look now at how the brain emerges and changes over the course of development.

Development of the Brain

A second widespread myth about the brain is that it fully matures within the first few years of life and that its development can best be nurtured by bombarding it with as much stimulation as possible—reading instruction, violin lessons, art classes, and so on—before its owner ever reaches kindergarten. Nothing could be further from the truth. Although much of the brain's development occurs before birth and the first few years after birth, the brain continues to develop in important ways throughout childhood, adolescence, and early adulthood. Furthermore, the kinds of experiences that nurture the brain's early development tend to be fairly normal ones, *not* nonstop "enrichment" activities that leave both children and their parents exhausted.

Prenatal Development

About 25 days after conception, the brain first emerges as a tiny tube. The tube grows longer and begins to fold inward to make pockets. Three chambers appear, and these eventually become the forebrain, midbrain, and hindbrain. Neurons quickly form and reproduce in the inner part of the tube; between the 5th and 20th weeks of prenatal development, they do so at the astounding rate of 50,000 to 100,000 new cells per second (M. Diamond & Hopson, 1998). The vast majority of the neurons a person will ever have—but certainly not all of them—are formed at this time (Bruer, 1999; C. A. Nelson, Thomas, & de Haan, 2006; R. A. Thompson & Nelson, 2001).

In the second trimester of prenatal development, the neurons migrate to various locations, drawn by a variety of chemicals and supported in their journeys by glial cells. On their arrival, they send out dendrites and axons in an effort to connect with one another. Those that make contact survive and begin to take on particular functions, whereas those that don't (about half of them) tend to die off (M. Diamond & Hopson, 1998; Goldman-Rakic, 1986; Huttenlocher, 1993). Such deaths are not to be mourned, however. Programming human beings to overproduce neurons is apparently Mother Nature's way of ensuring that the brain will have a sufficient number with which to work. The excess ones are unnecessary and can quite reasonably be discarded.

Development in Infancy and Early Childhood

Between birth and age 3, the brain more than triples in size, with much of the increase being due to a rapid proliferation of glial cells (Koob, 2009; Lenroot & Giedd, 2007). The cerebral cortex is the least mature part of the brain at birth, and cortical changes that occur in infancy and early childhood probably account for many of the advancements we see in children's thinking, reasoning, and self-control (M. A. Bell, Wolfe, & Adkins, 2007; M. I. Posner & Rothbart, 2007; Quartz & Sejnowski, 1997).

Several significant processes characterize brain development in the early years: synaptogenesis, differentiation, synaptic pruning, and myelination.

Synaptogenesis

Neurons begin to form synapses well before birth. But shortly after birth, the rate of synapse formation increases dramatically. Neurons sprout new dendrites going in many directions, and so they come into contact with a great many of their neighbors. Thanks to this process of **synaptogenesis**, young children have many more synapses than adults do. Eventually, the rapid proliferation of synapses comes to a halt. Exactly when it does so varies for different parts of the brain; for instance, synapses reach their peak in the auditory cortex (temporal lobes) at about 3 months, in the visual cortex (occipital lobes) at about 12 months, and in the frontal lobes at age 2 or 3 (Bauer, DeBoer, & Lukowski, 2007; Bruer, 1999; Byrnes, 2001; Huttenlocher, 1979, 1990).

Differentiation

As neurons form synapses with one another, they also begin to take on particular functions (McCall & Plemons, 2001; Neville & Bruer, 2001). Through this process, known as **differentiation**, neurons become specialists, assuming some duties and steering clear of others.

Synaptic Pruning

As children encounter a wide variety of stimuli and experiences in their daily lives, some synapses come in quite handy and are used repeatedly. Other synapses are largely irrelevant and useless, and these gradually disintegrate—a process known as **synaptic pruning**. In fact, the system seems to be set up to *guarantee* that synaptic pruning occurs. Neurons require chemical substances known as *trophic factors* for their survival and well-being, and by transmitting messages to other neurons, they cause the recipients to secrete such chemicals. If neurons regularly receive trophic factors from the same sources, they form stable synapses with those sources. If they receive trophic factors from some neurons but not others, they pull their axons away from the "unsupportive" ones. And if neurons are so "unstimulating" that they rarely excite any of their neighbors, they may wither and die (Byrnes, 2001). In some areas of the brain, the period

of intensive synaptic pruning occurs fairly early (e.g., in the preschool or early elementary years); in other areas, it begins later and continues until well into adolescence (Bauer et al., 2007; Bruer, 1999; Huttenlocher & Dabholkar, 1997).

Why do our brains create a great many synapses, only to eliminate a sizable proportion of them later on? In the case of synapses, more isn't necessarily better. Theorists speculate that by generating more synapses than we'll ever need, we have the potential to adapt to a wide variety of conditions and circumstances. As we encounter certain regularities in our environment, we find that some synaptic connections are counterproductive because they aren't consistent with what we typically encounter in the world or with how we typically need to respond to it. In fact, effective learning and behaving require not only that we think and do certain things but also that we *not* think or do *other* things—in other words, that we inhibit certain thoughts and actions. Synaptic pruning, then, may be Mother Nature's way of making our brains more efficient (Bryck & Fisher, 2012; Haier, 2001; C. A. Nelson et al., 2006).

Myelination

As noted earlier, a neuron's axon is in some cases covered with a myelin sheath, which greatly speeds up the rate with which an electrical charge travels along the axon. When neurons first form, they have no myelin; this substance arrives a bit later, courtesy of glial cells. The process of coating axons, known as **myelination**, occurs gradually over time. Some myelination begins near the end of the prenatal period (e.g., this is true in certain areas necessary for basic survival), but much of it occurs in the first few years after birth, with different areas becoming myelinated in a predictable sequence. In general, this increasing myelination of neurons enhances the brain's capacity to respond to the world more quickly, efficiently, and intelligently (Bryck & Fisher, 2012; M. Diamond & Hopson, 1998; Jung & Haier, 2007).

Development in Middle Childhood, Adolescence, and Adulthood

Especially in the cortex, synaptic pruning continues into the middle childhood and adolescent years—but with many *new* synapses also appearing in early puberty—and myelination continues into the twenties or beyond (Bauer et al., 2007; Bryck & Fisher, 2012; McGivern, Andersen, Byrd, Mutter, & Reilly, 2002; Merzenich, 2001; Steinberg, 2009). Several parts of the brain—notably the frontal and temporal lobes, hippocampus, amygdala, and corpus callosum, all of which play key roles in thinking and learning—increase significantly in size from middle childhood until late adolescence or adulthood (Giedd, Blumenthal, et al., 1999; Lenroot & Giedd, 2007; Sowell & Jernigan, 1998; E. F. Walker, 2002). The frontal lobes show evidence of considerable maturation during late adolescence and early adulthood, possibly enabling increasing facility in such areas as attention, planning, and impulse control (Luna & Sweeney, 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Steinberg, 2009).

An underlying message in the preceding paragraph is that *adolescents' brains are not yet adult brains.* Puberty brings changes in hormone levels (e.g., estrogen, testosterone) and certain neurotransmitters that affect the continuing maturation of brain structures (Bauer et al., 2007; Kolb, Gibb, & Robinson, 2003; E. F. Walker, 2002). Also accompanying puberty are significant changes in brain regions that play a role in pleasure seeking, potentially heightening the desire for enjoyable activities and immediate rewards. Only later, perhaps in the late teens or early twenties, do regions of the prefrontal cortex that support rational decision making and self-restraint fully mature (Figner & Weber, 2011; Luna, Paulsen, Padmanabhan, & Geier, 2013; Somerville,

Jones, & Casey, 2010). For such reasons, many adolescents have trouble planning ahead and controlling their impulses (Spear, 2007; Steinberg, Cauffman, Woolard, Graham, & Banich, 2009). In addition, they tend to make choices based on emotions ("This will be fun") rather than on logic ("There's a high probability of a bad outcome") (Cleveland, Gibbons, Gerrard, Pomery, & Brody, 2005; V. F. Reyna & Farley, 2006; Steinberg, 2007). Thus, adolescent risk taking is most common in social contexts, where having fun is typically a high priority and it's easy to get swept away by what peers are doing or suggesting.

Recall how Loved One's symptoms, which were minor in his early years, intensified in high school. In most cases, bipolar disorder and schizophrenia don't appear until adolescence or early adulthood. Such disorders seem to be caused, at least in part, by abnormal brain structures or neurotransmitter levels—abnormalities that don't emerge, or at least don't have much effect, until after puberty (Benes, 2007; N. R. Carlson, 1999; Giedd, Jeffries, et al., 1999; Jacobsen, Giedd, Berquin, et al., 1997; Jacobsen, Giedd, Castellanos, et al., 1997).

Factors Influencing Brain Development

Heredity certainly plays a role in brain development, guiding such processes as cell migration, synaptogenesis, and myelination. For the most part, heredity ensures that things go right as the brain continues to grow and restructure itself. Occasionally, however, flawed genetic instructions can cause things to go wrong, leading to such disabilities as dyslexia, schizophrenia, and Down syndrome.

Environmental factors influence brain development as well. One important factor is nutrition both before and after birth, which can affect the production and myelination of neurons and the growth of glial cells (D. Benton, 2008; Byrnes, 2001; Sigman & Whaley, 1998). High levels of environmental toxins (e.g., lead, mercury, and pesticides) can also have a sizable impact on brain development, especially during the prenatal period and in the first few years after birth (Hubbs-Tait, Nation, Krebs, & Bellinger, 2005; Koger, Schettler, & Weiss, 2005). And when future mothers consume large amounts of alcohol during pregnancy, their children often develop *fetal alcohol syndrome,* a condition characterized by distinctive facial features, poor motor coordination, delayed language, and intellectual disabilities (Mattson & Riley, 1998).

People's experiences, too, make a difference. For instance, the family environment in which children live—perhaps warm and nurturing, on the one hand, or harsh and abusive, on the other—affects the ways in which the brain structures itself (Ayoub & Rappolt-Schlichtmann, 2007; Repetti, Taylor, & Saxbe, 2007). And new challenges and learning opportunities—age-appropriate ones, of course—seem to enhance brain functioning, in part by nourishing existing neurons, synapses, and glial cells and in part by stimulating the growth of new ones (Koob, 2009; C. A. Nelson et al., 2006). For example, opportunities to learn new skills—perhaps how to read, use an abacus, play a musical instrument, or juggle—result in noticeable differences in the size, organization, or functioning of relevant brain structures (Castro-Caldas et al., 1999; Draganski et al., 2004; Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; K. L. Hyde et al., 2009; Kitayama, 2013). To the extent that the brain adapts itself in such ways to different circumstances and experiences, we say that it has **plasticity**.

Researchers have increasingly come to realize that heredity and environment interact in their influences in ways we can probably never disentangle. First and foremost, genes need environmental support in order to do their work. For example, children endowed with especially "smart" genes are apt to have maximal neurological development only if reasonably good nutrition and

environmental stimulation support such development (Sigman & Whaley, 1998; Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003). Second, children tend to seek out environmental conditions that match their inherited abilities (Nisbett et al., 2012; Tucker-Drob, Briley, & Harden, 2013). For example, children who inherit exceptional quantitative reasoning ability may enroll in advanced math courses and in other ways nurture their inherited talent. Children with average quantitative ability are less likely to take on such challenges and thus have fewer opportunities to develop their mathematical skills and the brain structures that underlie them. Finally, some genetically driven neurological changes seem to be especially sensitive to environmental influences during particular points in development—a form of heredity–environment interaction we turn to now.

To What Extent Are There Critical or Sensitive Periods in Brain Development?

Although the human brain is fairly adaptable to changing circumstances, it can't always bounce back when the environment offers too little stimulation or consistently presents the wrong kind of stimulation. In some cases, the *timing* of environmental stimulation (or lack thereof) makes a considerable difference. For example, consider this intriguing finding: When accomplished musicians play their musical instruments, those who began their musical training before age 10 show greater activation in a certain part of their brains than those who began their training at an older age (Elbert et al., 1995). One group doesn't necessarily play better than the other, but the later-trained musicians appear to have missed a window of opportunity for fully developing a certain brain area that the earlier-trained musicians are using.

For some cognitive abilities, there appear to be **critical periods**—limited age ranges in which particular kinds of environmental stimulation are *essential* for normal neurological development. The development of certain other cognitive abilities might better be characterized as having **sensitive periods**: Environmental experiences have a greater impact during a certain age range, but the windows of opportunity don't necessarily slam shut at the end of that time period.

Researchers have found evidence for critical periods in the development of visual perception (Bruer, 1999; Hubel, Wiesel, & Levay, 1977; Levay, Wiesel, & Hubel, 1980). For instance, when children are born with cataracts that prevent normal vision, the timing of corrective surgery has a major impact on the development of certain brain areas that support visual processing. If the cataracts are surgically removed at an early age—say, by age 2—children develop relatively normal vision, but if surgery is postponed until much later, children have only limited visual abilities and in some instances remain functionally blind (Bruer, 1999; Maurer, Lewis, Brent, & Levin, 1999; Ostrovsky, Andalman, & Sinha, 2006).

There may be critical or sensitive periods for some aspects of language development as well. Children who have little or no exposure to language in the early years often have trouble acquiring language later on, even with intensive language instruction (Curtiss, 1977; Newport, 1990). Furthermore, in the first few days and weeks of life, infants can discriminate among speech sounds used in a wide variety of languages, but by the time they're 6 months old, they can detect only those differences important in the language(s) spoken around them (P. K. Kuhl, Tsao, & Liu, 2003; P. K. Kuhl, Williams, & Lacerda, 1992). As an example, the English language treats "L" and "R" as two separate sounds, whereas Japanese clumps them together into a single sound; thus, children in English-speaking countries continue to hear the difference between them, whereas Japanese children quickly lose the ability to tell them apart. I think back with fondness to one

of my apartment mates in graduate school, a Japanese woman named Kikuko who didn't learn English until grade school. Kikuko often talked about taking her *umblella* with her on rainy days and about counting the *raps* she completed while running the track around the gym.

Additional evidence for critical or sensitive periods in language development comes from people who learn a second language. Typically, people learn how to pronounce a second language flawlessly only if they study it before midadolescence or, even better, in the preschool or early elementary years (Bialystok, 1994a; Flege, Munro, & MacKay, 1995; M. S. C. Thomas & Johnson, 2008). Children also tend to have a much easier time mastering complex aspects of a second language's syntax when they're immersed in the language within the first 5 to 10 years of life (Bialystok, 1994a, 1994b; Birdsong, 2006; Bortfeld & Whitehurst, 2001). The effects of age on language learning are especially noticeable when the second language is phonetically and syntactically quite different from the first (Bialystok, 1994a; Doupe & Kuhl, 1999; Strozer, 1994).

So let's return to our earlier question: To what extent are there critical or sensitive periods in brain development? It appears that fairly rigid critical periods exist for certain basic abilities such as visual perception and certain aspects of language development. Even in these domains, however, the windows of opportunity are different for more specific abilities. For instance, there are different time frames for the development of color vision, motion perception, and depth perception, and different time frames for sound discrimination, pronunciation, and acquisition of syntactic structures (Bruer, 1999; Neville & Bruer, 2001; M. S. C. Thomas & Johnson, 2008). Furthermore, the windows typically close only gradually over a prolonged period and in some cases stay open at least a crack for a very long time, especially if the right kinds of experiences are provided.

However, for most of the topics and skills taught in schools and universities—even such basic skills as reading and arithmetic—there are virtually *no* critical or sensitive periods (Bavelier & Neville, 2002; McCall & Plemons, 2001; C. A. Nelson et al., 2006). Oftentimes people become quite proficient in topics or skills that they don't begin to tackle until they're teenagers or adults. For example, I didn't learn to drive until I was 16, didn't begin to study psychology until I reached college, and didn't begin to play racquetball until I was in graduate school, but with time and practice, I've acquired considerable mastery in each of these domains.

Experience-Expectant versus Experience-Dependent Plasticity

Exactly when is early experience important, and when is it *not* important? Greenough, Black, and Wallace (1987) have made a distinction that can help us make sense of what appear to be conflicting data. It seems that Mother Nature has helped our brains evolve in such a way that we can adapt to the specific physical and cultural environments in which we find ourselves, but she assumes that we'll have *some* stimulation early on to shape brain development. For skills that human beings have possessed for many millennia, such as visual perception and language, the brain is **experience-expectant**: It uses the experiences that human beings encounter in virtually any environment to fine-tune its powers. For instance, although the brain is initially capable of interpreting visual signals from both eyes, it will restructure itself to compensate for a malfunctioning one (Bavelier & Neville, 2002; T. V. Mitchell, 2007). And although it comes equipped with what it needs to discriminate among many different speech sounds, it quickly learns to ignore subtle differences that are irrelevant for making sense of its native language, paving the way for more efficient discriminations among sounds that *are* important for language comprehension. Quite possibly, the phenomena of synaptogenesis, differentiation, and synaptic pruning

provide the mechanisms by which the brain initially sets itself up to accommodate a wide variety of environments and then begins to zero in on the particular environment in which it actually finds itself (Bruer & Greenough, 2001; P. K. Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005; M. S. C. Thomas & Johnson, 2008). Although such zeroing-in obviously enhances the brain's ability to deal efficiently with common, everyday situations (e.g., understanding and speaking in one's native language), it may interfere with the brain's ability to override its usual ways of thinking in order to do something very different later on (e.g., learning a second language).

Many other content domains and skill areas—for instance, reading, driving a car, psychology, racquetball—are such recent additions to human culture (and none of these appears in *all* cultures) that Mother Nature has had neither the time nor inclination to make them part of our evolutionary heritage (Bruer, 1997, 1999; Byrnes, 2001; M. Wolf, Gottwald, Galante, Norton, & Miller, 2009). Domains and skills that are unique to particular cultures and social groups are **experience-dependent**: They emerge only when environmental conditions nurture them, and they can presumably be acquired at almost any age. In fact, by strengthening weak synapses and forming new ones, human beings and other animals retain considerable experience-dependent plasticity throughout the lifespan (Greenough et al., 1987; Maguire et al., 2000; Merzenich, 2001; C. A Nelson et al., 2006). For example, at age 85, my mother-in-law moved from Arizona to be near us in our present home in New Hampshire. She easily learned the knowledge and skills she needed to survive and thrive in her new community, including how to get to the bank and grocery store, which neighbors had talents and interests similar to her own, and what political issues were simmering in town and across the state.

To What Extent Is the Brain "Prewired" to Know or Learn Things?

Let's look once again at language. Speaking and understanding language is a miraculous accomplishment indeed; children must master not only the subtle motor movements involved in producing various consonants and vowels but also tens of thousands of word meanings plus syntactical structures so numerous and multifaceted that even linguists have been hard-pressed to identify and catalog them all. How children master language as quickly as they do remains one of the big mysteries of child development. Many psychologists believe that, although children obviously aren't born knowing a particular language, they *are* born with some predispositions that assist them in acquiring whichever language they hear spoken around them. For instance, as noted earlier, young infants can detect subtle differences among very similar speech sounds. Furthermore, they can divide a steady stream of sound into small segments (e.g., syllables), identify common patterns in what they hear, and seem to have a few built-in concepts (e.g., colors such as red, pink, and yellow) that predispose them to categorize their experiences in certain ways. They may also have a *Universal Grammar,* a set of parameters that predisposes them to form certain kinds of grammatical structures but not others (Chomsky, 2006; Gopnik, 1997; D. Lightfoot, 1999; O'Grady, 1997; Pinker, 2007).

Some theorists have suggested that human beings may be prewired with respect to other domains as well. Consider these findings from research with infants:

- Within 24 hours after birth, infants have some ability to discriminate between objects that are close to them versus objects that are farther away (A. Slater, Mattock, & Brown, 1990). It's as if they can judge distance long before they have much opportunity to *learn* about distance.

- Infants as young as 1 or 2 days old may imitate an adult's facial expressions—perhaps pursing their lips, opening their mouths, or sticking out their tongues (T. F. Field, Woodson, Greenberg, & Cohen, 1982; Meltzoff & Moore, 1977; Reissland, 1988). It's as if they already connect certain things they see other people do with certain things that they themselves can do. In fact, evidence is emerging that some species—including human beings—have certain neurons that fire either when they perform a particular action themselves *or* when they watch *someone else* perform it (Gallese, Gernsbacher, Heyes, Hickok, & Iacoboni, 2011; Murata et al., 1997; Rizzolatti & Sinigaglia, 2008). Such neurons, known as **mirror neurons**, might explain why infants can imitate others so early in life: Some of the same neurons are involved when they watch another person's behavior and when they engage in the behavior themselves.
- By 3 or 4 months, infants show signs of surprise when one solid object passes directly through another one, when an object seems to be suspended in midair, or when an object appears to move immediately from one place to another without traveling across the intervening space to get there (Baillargeon, 1994; Spelke, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992). It appears, then, that young infants know that objects are substantive entities with definite boundaries, that objects will fall unless something holds them up, and that movements of objects across space are continuous and somewhat predictable.

Such findings suggest to some theorists that infants have some biologically built-in **core knowledge** about the physical world (e.g., Baillargeon, 2004; M. Cole & Hatano, 2007; Spelke, 2000). Knowledge of this kind would have an evolutionary advantage, of course—it would give infants a head start in learning about their environment—and evidence for it has been observed in other species as well (Spelke, 2000).

Nevertheless, the extent to which the human brain is hardwired with certain knowledge—or perhaps with predispositions to acquire that knowledge—is an unresolved issue and will likely remain so for quite some time. Unless researchers can assess infants' knowledge at the very moment of birth, they can't rule out the possibility that experience and practice, rather than built-in knowledge, account for infants' early capabilities. Just imagine a couple of scientists in lab coats appearing in a hospital delivery room to ask if they can whisk a new baby away for a "research project." I seriously doubt that they'd find many new parents willing to sign the necessary permission forms.

The Neurological Basis of Learning

So how and where, from a physiological standpoint, does learning occur? Many theorists believe that the basis for learning lies in changes in interconnections among neurons—in particular, in the strengthening or weakening of existing synapses or the formation of new ones (e.g., Hebb, 1949; Lichtman, 2001; M. I. Posner & Rothbart, 2007; Trachtenberg et al., 2002). A second phenomenon may be involved as well. Until recently, it was common "knowledge" that all the neurons a person would ever own are produced in the first few weeks of the prenatal period. Some researchers have found, however, that **neurogenesis**—the formation of new neurons—continues throughout the lifespan in a particular part of the hippocampus and possibly also in certain regions of the frontal and parietal lobes. New learning experiences appear to enhance the survival rate and maturation of the young neurons; without such experiences, these neurons slowly die away (Gould, Beylin, Tanapat, Reeves, & Shors, 1999; Leuner et al., 2004; C. A. Nelson et al., 2006; Sapolsky, 1999; Spalding et al., 2013).

It also appears that certain star-shaped glial cells known as **astrocytes** are just as important as neurons in learning and memory—possibly even more important. In human beings, astrocytes far outnumber neurons, have countless chemically mediated connections with one another and with neurons, and seem to have considerable control over what neurons do and don't do and how much neurons communicate with one another. A normal brain produces many new astrocytes throughout the lifespan (X. Han et al., 2013; Koob, 2009; Oberheim et al., 2009; Verkhratsky & Butt, 2007).

An additional consideration is the fact that most newly acquired knowledge and skills need time to "firm up"—a process called **consolidation** (e.g., Rasch & Born, 2008; M. P. Walker, 2005; Wixted, 2005). Consolidation seems to be a very gradual process that might take several minutes, hours, or days, or perhaps even longer. Neuroscientists are still speculating about the specific neurological mechanisms that underlie consolidation; possibly it involves some sort of low-level, unconscious activation, rehearsal, or strengthening of newly formed connections (Bauer et al., 2007; Rasch & Born, 2008; D. J. Siegel, 2012). In any case, head injuries and other physically traumatic events can significantly disrupt it. For example, accident victims who suffer serious head traumas often can't remember events immediately leading up to their accidents, and sometimes they also forget events that occurred a few days or weeks beforehand. Such **retrograde amnesia** is especially common when someone is unconscious for a short time following the injury, presumably because the person is temporarily unable to think about and consolidate things that have recently occurred (D. J. Siegel, 2012; Squire & Alvarez, 1998; Wixted, 2005).

As for *where* learning occurs, the answer is: *many places.* The frontal lobes are active when we must pay attention to and think about new information and events, and all of the lobes of the cortex may be active to a greater or lesser extent in interpreting new input in light of previously acquired knowledge (Byrnes, 2001; Cacioppo et al., 2007; Huey, Krueger, & Grafman, 2006). The small, seahorse-shaped hippocampus also seems to be a central figure in thinking and learning, binding together information it receives from various parts of the brain to create and then consolidate new memories (Bauer, 2002; Davachi & Dobbins, 2008; Shohamy & Turk-Browne, 2013; Squire & Alvarez, 1998). And the hippocampus's neighbor in the limbic system, the amygdala, is probably instrumental in the preverbal, emotional memories that very young children form, and throughout the lifespan it continues to influence what people pay attention to and how they interpret new experiences (Cunningham & Brosch, 2012; LeDoux, 1998; Wisner Fries & Pollak, 2007).

Even as researchers pin down how and where learning occurs, we must remember that knowledge of brain anatomy and physiology doesn't begin to tell us everything we need to know about learning, let alone about how we can best foster and enhance it in educational settings. We now look at what research about the brain does and doesn't tell us about appropriate and effective educational practices.

Educational Implications of Brain Research

Extolling recent advances in brain research, many well-intentioned individuals have drawn unwarranted inferences about its educational implications. For instance, you might hear people speaking of "building better brains," designing a "brain-based curriculum," or "teaching to the right brain." Such statements often reflect misconceptions about how the brain works. Although

much of what researchers have learned about brain functioning is still somewhat tentative and controversial, following are several conclusions we can draw with confidence.

◆ *Some loss of synapses is both inevitable and desirable.* Apparently in an effort to preserve as many of a child's early synapses as possible, some writers have suggested that infants and young children be immersed in stimulation-rich environments that get them off to a strong start in academics, athletics, and the arts. Yet synaptic pruning is inevitable, because synapses must compete for a limited supply of the trophic factors that ensure their survival. Furthermore, pruning is often beneficial rather than detrimental, because it eliminates useless synapses and thereby enhances the brain's efficiency. The sequence of synaptogenesis and synaptic pruning is a primary means by which Mother Nature ensures plasticity and adaptability in human functioning. In fact, much learning and many advances in cognitive abilities are possible only *after* a good deal of synaptic pruning has already occurred (Bruer, 1999).

◆ *Many environments nurture normal brain development in experience-expectant domains.* In domains where development depends on particular kinds of stimulation at particular ages—that is, in *experience-expectant* domains—the necessary stimulation is found in experiences that children encounter in virtually any culture. For instance, to acquire normal binocular vision, children need regular and balanced visual input to both eyes, and to acquire normal facility with language, children need ongoing exposure to a language, either spoken or manually signed (Bruer, 1999; McCall & Plemons, 2001; Newport, 1990). Such experiences can be found in virtually all social and cultural groups, even in remote tribal groups in developing nations.

◆ *Throughout life, enriching environments and experiences can greatly enhance development in experience-dependent domains.* Although most sociocultural environments sufficiently nurture experience-*expectant* abilities, some environmental conditions are especially beneficial for nurturing experience-*dependent* ones. For example, children often make greater cognitive gains—for instance, they have more knowledge and skills, and they earn higher scores on intelligence tests—if they attend good preschool programs (NICHD Early Child Care Research Network, 2002; Nisbett et al., 2012; Schweinhart et al., 2005; Zigler, 2003). However, such gains made in the early years tend to diminish over time, and may disappear altogether, unless children continue to have stimulating experiences during the school years (Bronfenbrenner, 1999; Brooks-Gunn, 2003; Farran, 2001; Raudenbush, 2009). Educators and policy makers mustn't put all of their eggs in one age-specific basket; nurturance of cognitive development has to be a long-term enterprise.

◆ *In developmental domains characterized by critical or sensitive periods, the windows of opportunity often remain at least a crack open.* The concepts of *critical period* and *sensitive period* tell us the best times for particular abilities to be nurtured, but they don't necessarily tell us the *only* times. Sometimes, for a variety of reasons, children have little or no exposure to appropriate stimulation during the optimal time frame; for instance, children may not get needed cataract surgery until their families can afford it, and children who are congenitally deaf may not encounter a language they can actually perceive (e.g., American Sign Language) until they reach school age. Rather than fret over what should have happened but didn't, researchers and educators can better serve young people who have missed critical experiences by devising and implementing interventions that enable those individuals to make up at least some of the lost ground (Bruer, 1999; Feuerstein, Feuerstein, & Falik, 2010).

I must include one important caveat here, however: A *very* critical period is the prenatal period, especially the first few months after conception, when adequate nutrition and protection from environmental hazards (lead dust, mercury, alcohol, etc.) are essential if the brain is to get off to a good start. The adverse effects of poor nutrition and environmental insults during this time period appear to be irreversible.

◆ *There is no such thing as teaching to the "left brain" or to the "right brain."* Some writers have suggested that many adults and children specialize in one hemisphere or the other, to the point of being largely "left-brain" or "right-brain" thinkers and learners, and so they urge educators to accommodate the hemispheric preferences of every student. But as we've seen, both hemispheres work in close collaboration in virtually all thinking and learning tasks. In the absence of performing surgical lobotomies (which I obviously don't recommend), attempts to train one side exclusively will be in vain.

◆ *Good sleeping habits and regular physical exercise enhance brain functioning.* As you well know, a good night's sleep improves mental alertness and can help people ward off germs that intend to do them harm. But in addition, sleep supports the brain's efforts to consolidate new memories, rendering them more memorable over the long run (Hu, Stylos-Allan, & Walker, 2006; Payne & Kensinger, 2010; Rasch & Born, 2008).

Physical exercise, too, appears to be beneficial, especially if it includes aerobic activities that keep one's cardiovascular system in good working order. A particular benefit of exercise is that it enhances the functioning of certain brain structures that help people keep their minds productively engaged in whatever task is at hand (Castelli, Hillman, Buck, & Erwin, 2007; K. I. Erickson et al., 2011; Tomporowski, Davis, Miller, & Naglieri, 2008).

◆ *Brain research can help us refine our theories of learning and cognition, but it can't tell us very much about what to teach or how best to teach it.* As researchers continue to learn more about the architecture and functioning of the brain, they sometimes find evidence that either supports or refutes various psychological explanations of how people learn and think (e.g., Byrnes, 2007; Varma, McCandliss, & Schwartz, 2008). And as psychologists, in turn, refine their theories of learning and cognition, they can gradually get a better handle on the kinds of instructional methods and therapeutic interventions that are most likely to foster effective learning and productive behavior.

Nevertheless, we may never be able to boil down specific psychological phenomena—thoughts, knowledge, interpretations, and so on—into precise physiological entities (e.g., see G. A. Miller, 2010; Poldrack, 2010; Veenman, 2011). Brain research is unlikely to tell us what information and skills are most important for people to have; such things are often culture specific, and decisions about how to prioritize them are value laden (L. Bloom & Tinker, 2001; Chalmers, 1996; H. Gardner, 2000). And up to this point, brain research has yielded only a few vague clues about how we might best help learners acquire important information and skills (Bandura, 2006; D. Kuhn & Franklin, 2006; Varma et al., 2008). Fortunately, as you'll discover in the chapters that follow, psychological theories of learning—theories derived from studies of human behavior rather than from brain anatomy and physiology—have a great deal to offer as we work to identify effective instructional and therapeutic techniques.

Summary

Messages travel through the human nervous system by way of both (a) electrical transmissions that run through individual neurons and (b) chemical transmissions that traverse synapses between neurons. Synapses in the spinal cord are responsible for a few basic reflexes, but by and large the brain is the coordination and decision-making center for the body.

Using a growing arsenal of research methods, scientists have learned a great deal about how the brain works. In human beings, the largest and most recently evolved part of the brain—the *forebrain*—predominates in consciousness, thinking, learning, and the many distinctly human mental activities in which people engage. Even small, seemingly simple tasks (e.g., recognizing and understanding particular words) typically involve many parts of the brain in both hemispheres working together.

The beginnings of the brain emerge late in the first month of prenatal development; by the second trimester, most of the neurons a person will ever possess have formed and are migrating to their final locations. Synapses among neurons begin to form before birth; shortly after birth, the rate of synapse formation increases dramatically, so much so that children have many more synapses than adults do. Over the course of childhood and adolescence, the brain cuts back (i.e., *prunes*) little-used synapses, apparently as a means of adapting to its environment and increasing its efficiency. Although a good deal of brain development occurs during the prenatal period and early childhood years, brain structures and neurotransmitters continue to undergo significant changes in adolescence and early adulthood. Genetic instructions largely drive general developmental changes in the brain, but nutrition, environmental toxins, and new learning experiences influence brain development as well.

Researchers have found evidence for critical or sensitive periods in the development of some basic, long-standing human abilities (e.g., visual perception and language). But many recent human achievements (e.g., literacy and mathematics) can probably be acquired at any age, and certainly the ability to acquire new knowledge and skills remains throughout life. Some theorists hypothesize that certain kinds of knowledge essential for people's basic survival (e.g., certain elements of language, basic knowledge about the physical world)—or at least predispositions to acquire these things quickly and easily—may be biologically built in.

Many theorists believe that learning primarily involves the modification of existing synapses and the creation of new ones, along with the occasional formation of new neurons. It is becoming increasingly clear, however, that certain star-shaped glial cells known as astrocytes also play key roles in learning and memory.

Some well-meaning educators have drawn unwarranted implications from brain research. The early years are important, but providing intensive, structured programs for infants and preschoolers is unlikely to prevent synaptic pruning, and any other potential benefits of such programs for neurological development have yet to be demonstrated. Furthermore, efforts to teach to the "left brain" or "right brain" are ultimately in vain because the two hemispheres collaborate in virtually any activity. Findings from brain research have been useful in helping psychologists refine their theoretical explanations of learning and cognition, but they haven't yet offered much guidance regarding effective instructional practices.