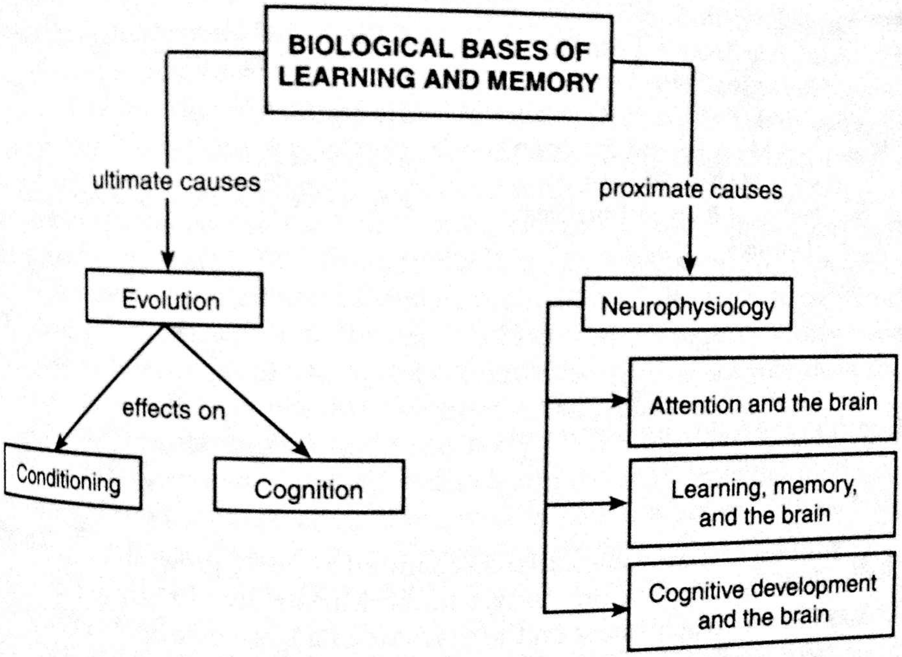
Part V: Learning and Biology

8

Biological Bases of Learning and Memory



Implications of Evolution

1. Humans may be predisposed to certain fears.
2. Behaviors for which there is no predisposition to learn may be difficult to establish.
3. Previously adaptive behavior may be difficult to overcome.
4. Actions associated with decreased fitness in ancestral populations may be difficult to establish.

Implications of Neurophysiology

1. Cognitive functions are differentiated.
2. The brain is relatively plastic in nature.
3. Language may be biologically pre-programmed.
4. Learning disabilities may have a neurological basis.

Consider the following scenarios.

- ***Twins***

Miriam and Mercedes, twins separated at birth, grew up in communities that were different on many counts. Miriam lived with her adoptive family in a small apartment on the east side of a large metropolitan area. She attended a nearby, crowded urban school that, except for math class, she was glad to leave upon graduating. Mercedes, by contrast, made her home in a rambling farmhouse located far from the nearest neighbors. She rose early on a daily basis to do chores before the school bus picked her up at 7 A.M. She, like her sister, excelled in math at the rural school she attended.

As adults, the twins chose engineering careers, married men named Bob, and enrolled, at the sponsorship of their respective companies, in a management training seminar, where they met for the first time.

- ***Brain Damage***

Mario was about 4 years old when a severe viral infection irreparably damaged part of his brain. Doctors were unsure whether he would ever recover his speech, much less learn to any normal extent. However, within months, he had begun talking again, and by first grade, appeared to be like every other first grader in his class.

What do these scenarios have in common? On the surface, perhaps not much. But they raise similar questions about learning that have not yet been accounted for in detail by any learning theory. That is, to what extent is learning governed by biological factors? Is it just coincidence that Mercedes and Miriam excelled in the same academic subject, chose the same career, and enrolled in the same job-related training program? Can their behavior be satisfactorily explained by reference to contingencies of reinforcement in their respective learning histories? Can similar conditions be found in their environments that would account for particularly well-learned mental models in mathematics? Or is their genetic inheritance responsible to some degree for the way their lives play out?

Similarly, most of us carry an intuitive belief that the brain is somehow implicated in learning. Children with Down syndrome, for example, rarely attain the mental functioning of normal children. At the other end of the age continuum, Alzheimer's disease, associated with a severe reduction of a particular neurotransmitter in the brain cortex, can cause extensive memory loss and mental impairment. Yet Mario, in the Brain Damage scenario, appears to fully overcome the impairment caused by brain injury. (Although this scenario is fictional, it is consistent with the results of neurophysiological studies to be discussed in this chapter.) The question remains, then, What role does the brain play in learning, cognitive development, and memory retention?

Genetic inheritance and brain physiology are the focal points for two basic lines of biological research related to learning. Together with individual development and the adaptive significance of species characteristics, they correspond to the types of causes biologists seek as explanations for behavior (cf. Dewsbury, 1991). Consider, for example, the characteristic of binocular vision in humans. Depth perception can be explained in terms of the structure and placement of human eyes. Our eyes are set relatively close together in our heads, and their anatomical structure permits them to work together in creating the sensation of depth. When biologists provide such physiological explanations of phenomena, they assign proximate causes to behavior. In Mario's case, then, his return to normalcy might be attributed to proximate causes in that other parts of his brain assumed the functions of the damaged part.

Searching for environmental factors thought to influence behavior is also a matter of assigning proximate causes. So, for example, a teenage boy's preference for looking at pictures of nubile young women may be attributed to liking the pictures or to peer approval of this behavior. Both are proximate causes. In the Twins scenario, a reasonable explanation for the girls' mathematical talent might be found in their families' emphasis on and support for learning in math. These, too, would be proximate causes.

Explaining binocular vision only in terms of human anatomy and physiology, however, still leaves open the question of why humans developed the anatomical structures and processes that they have. In other words, why are our eyes set close together in our heads? Asking questions such as this are evolutionary psychologists in search of ultimate causes of human behavior. They look to evolution to provide the answers. With regard to binocular vision, for example, those ancestors who could distinguish depth were undoubtedly more successful at hunting prey and finding their way through a variety of terrains. These behaviors, in turn, proved to be adaptive in the overall struggle for survival. As a result, the genes governing close eye placement gradually dominated through a process of natural selection.

Understanding teenage boys' viewing preferences might also be enlightened by reference to ultimate causes. That is, sexual behavior in general is related to reproductive fitness in ancestral populations. In the Pleistocene environment, during which 99 percent of human evolution occurred (Cosmides, Tooby, & Barkow, 1992), the physical correlates of female nubility probably indicated a young woman of 15 to 18 years of age. Although the perception of a woman's sexual attractiveness in modern times is less dependent on age than it was in ancestral times, younger women are still likely to be seen as more sexually attractive than are older women (Symons, 1992). It stands to reason, then, that adolescent boys are attracted to pictures of nubile young women.

From two branches of biology, then, we see separate and distinct contributions to an overall understanding of the biological bases of human learning and behavior (Figure 8.1). Both are examined further in this chapter. In addition, however, the question is addressed as to what, if any, practical implications for instruction may be drawn from these two fields of study.

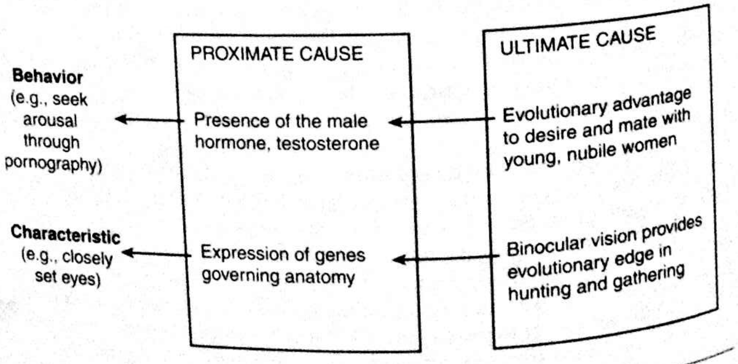


FIGURE 8.1 *Examples of Two Types of Biological Causes*

Chipman (1986) noted with concern that educators often adopt uncritically and inappropriately results from neuroscience research. She argued for more multilevel theorizing that will situate neurological interventions within an overall educational enterprise, since, "pills do not, after all, teach reading" (Chipman, 1986, p. 226). Bruer (1997) expressed a similar sentiment when he concluded that it was a bridge too far to suggest that particular educational activities will lead to specific changes in the brain. In light of these concerns, the intersection between biology and instruction is examined.

Ultimate Causes: Evolution and Behavior

It goes without saying that Charles Darwin's concept of natural selection in evolution lies at the very heart of sociobiology. The idea of evolution—that present living forms are descendents of long-extinct ancestors—had already been established prior to the publication in 1859 of Darwin's most famous work, *Origin of Species*. What Darwin contributed was a reasonable theory for how evolutionary changes come about. That is, he proposed a process of natural selection. In the struggle for existence, organisms that are perfectly adapted to their environments will survive unchanged. In conditions of less than perfect adaptation, however, those organisms that have traits enabling them to struggle more effectively than other organisms will pass on these genes to more offspring. Over many generations, some traits will be naturally selected over others, with these changes manifested in the genetic makeup and behavior of the organisms.

Evolutionary psychology rests on the assumption that the psychology of behavior is well informed by evolutionary biology. That is, "understanding the process that designed the human mind [is expected to] advance the discovery of its architecture"—neural, cognitive, and behavioral (Cosmides et al., 1992, p. 3). Evolutionary psychologists focus on evolved psychological mechanisms (Tooby & Cosmides, 1992), which are adaptations constructed by natural selection to serve some specific function associated with survival.

Two points are important to remember here. First, human history as we tend to think of it does not comprise much time from an evolutionary perspective—about one thousand years compared to the two million years humans spent as hunter-gatherers in the Pleistocene environment (Cosmides et al., 1992). As a consequence, evolved psychological mechanisms of the human mind are adapted to an ancient way of life, not to conditions present in the modern world. Indeed, evolutionary psychologists refer to today's world as an "evolutionary novel environment" and point out the risk in making inferences about evolution from observations of behavior that is adaptive in present conditions.

Second, evolutionary adaptations are both functional and specific. This means that a given structure, organ, or process was designed by selection to serve a specific function and thus solve a specific problem or natural selection pressure (Symons, 1992). There is no general function or mechanism for promoting gene survival. The goal of evolutionary psychology, then, becomes one of understanding the many domain-specific specialized functions of the mind, how these arose to solve the problems of survival, and what they might mean for human behavior.

Let us now take a closer look at some of the possible insights an evolutionary perspective might offer for theories of learning and behavior.

Evolution and Conditioning

Reflect back, for a moment, on the discussions in Chapters 1 and 2 of classical and operant conditioning. No hint was ever given that the laws of conditioning might be species-specific. Skinner, in fact, held just the opposite view. He believed strongly that learning proceeded in much the same way for all species. Whatever biological constraints could be identified (e.g., animals can hear only certain frequencies of sound and see only certain spectra of light) were assumed to be peripheral to learning.

Despite Skinner's assumption of, and belief in, general learning laws, others have not been so convinced. Students in my learning classes, for example, pose questions every semester about the limits of conditioning principles. Even before we discuss biological factors in learning, they wonder why pigeons learn to peck circles much faster than rats learn to press levers (both undergoing shaping in a Skinner box). Could the differences in performance be attributed to species-specific evolutionary differences—differences that predispose organisms to learning certain things? An evolutionary view of learning and behavior in effect integrates common notions of instinctive versus learned behavior. Some researchers have gone so far as to say that "this distinction [between learned and instinctive behavior] is completely spurious; you cannot have one without the other.... Learning itself may be the primary instinct" (Garcia, Brett, & Rusiniak, 1989, p. 200).

There is evidence now to suggest that both classical and operant conditioning are subject to biological influences. With respect to the former, results of studies on taste aversion indicate that animals are prepared to associate some conditioned stimuli with some unconditioned stimuli, but are not prepared to associate other conditioned stimuli with those unconditioned stimuli (Mowrer and Klein, 1989). Garcia and Koelling (1966) conducted the now-classic study in which this phenomenon was discovered.

In a 2 × 2 factorial design, Garcia and Koelling (1966) paired two conditioned stimuli (flavor and noise) with two unconditioned stimuli (a drug producing illness and a shock producing pain). Under the standard classical conditioning paradigm, the researchers expected the subjects (rats in this case) to avoid any conditioned stimulus that was associated with the consequences of illness or pain. What they found instead is summarized in Figure 8.2. The rats developed a strong aversion to saccharine-flavored water only when it coincided with illness. They continued to drink it when pain was the consequence. Likewise, rats who were shocked attempted to avoid the associated noise, but rats who were sickened paid no attention to it.

Varied replications of this study (e.g., Domjon, 1980; Garcia, Clarke, & Hankins, 1973) strengthened the conclusions that rats are genetically predisposed to these associations. Upon becoming sick, the rat is likely to attribute the cause of its distress to the most recent, novel substance ingested. In other words, "It must be something I ate," but since familiar foods had not previously caused illness, that something must be the most recent, unfamiliar food. Pet owners may recognize this same phenomenon in their animals. Shortly after eating a new kind of dog food I had purchased, my dog became ill. Although a kind of viral infection was later diagnosed, he thereafter refused to eat that brand of dog food.

Clearly, developing taste aversions to foods that cause illness and avoiding external cues associated with pain are adaptive mechanisms that increase an animal's fitness for survival. Based on the same logic, associations involved in phobias may also be both selective and adaptive (Lohordo & Droungas, 1989). Snakes and spiders were dangerous to pretechnological man. As a result, we may now be predisposed to fear them.

Like classically conditioned associations, operant behaviors appear to be influenced by biological factors. Breland and Breland (1961) coined the term *instinctive drift* after witnessing a deterioration of operant behavior in trained animals over an extended period of training. As part of an advertising gimmick, they trained pigs and raccoons to deposit coins in a piggy bank. They followed typical shaping and chaining procedures, using food as the

		Unconditioned Stimulus	
		Drug (producing illness)	Shock (producing pain)
Conditioned Stimulus	Flavor	**Strong Association**	No Results
	Noise	No Results	**Strong Association**

FIGURE 8.2 ***Results of Pairing Two Types of Conditioned Stimuli with Two Types of Unconditioned Stimuli***

Source: Modified from Garcia and Koelling (1996).

reinforcer. At first, the pigs and raccoons demonstrated flawless performance—picking up, on cue, a coin or two and depositing it in the receptacle that served as the piggy bank. With repeated trials, however, the pigs began to root at the coins. The raccoons, after initiating the procedure properly, would not release the coins into the bin, instead rubbing them together and dipping them in and out of the bin.

The Brelands hypothesized that the food reward elicited species-specific feeding patterns which ultimately interfered with the operant response being conditioned. With the notion of instinctive drift, they suggested that instinctive behaviors may eventually dominate operant behavior in many circumstances. Their results have been supported by studies investigating neural substrates of reinforcement (e.g., Vaccarino, Schiff, & Glickman, 1989). That is, significant correlations have been found between stimuli that serve as reinforcers and stimuli that elicit species-characteristic feeding patterns.

Evolution and Cognition

"Even simple organisms, such as scorpionflies and bluegill sunfish, must process information from their environment and make decisions on the basis of it if their interactions with…physical aspects of their environment are to be adaptive" (Crawford & Anderson, 1989). This suggests that human information-processing mechanisms may have evolved to reflect the types of problems faced by early humans in their ancestral environment.

As a means of studying evolutionary influences on cognition, Cosmides and her colleagues (Cosmides, 1989; Cosmides & Tooby, 1989, 1994, 1995; Tooby & Cosmides, 1989, 1992; Cosmides et al., 1992) conceptualized specialized learning mechanisms called Darwinian algorithms. Darwinian algorithms are presumed to be in the neural architecture (Crawford, 1993), and they constitute the psychological adaptations that have occurred in cognition over evolutionary time.

For example, recall from Chapter 4 the reasoning task that cognitive researchers have used to investigate context dependency in logical reasoning. Subjects are asked to reason from such rules as, "If there is a vowel on one side of the card, there should be an even number on the other side." While performance is poor on problems using the rule as stated, it improves dramatically when the rule is put into a familiar context (e.g., "If a purchase is greater than $30, the store manager's signature must be on the back of the receipt").

Schema theorists interpreted such results to support the context dependency of reasoning, but Cosmides has argued (cf. Cosmides & Tooby, 1989) that the results provide evidence of Darwinian algorithms. That is, ancestral humans must have evolved some cognitive mechanism that enabled them to rapidly and accurately detect cheaters on social contracts. This "detection of cheaters" mechanism is then assumed to account for the comparative ease with which problems can be solved using the store manager rule.

A focus on invariant cognitive mechanisms, rather than invariant behavior, highlights two important points made earlier in the chapter. First, not all behavior is assumed to be adaptive under current environmental conditions. Second, numerous, task-specific mental mechanisms are assumed to account for learning rather than a single, general mechanism. Remember from Chapter 3 that Estes (1988) has already cautioned cognitive scientists to expect their models of memory to be proved inadequate, because such models are currently based on a uniform, parallel processing computer metaphor. However, "organisms have not evolved general mechanisms for digestion; they have evolved particular devices for dealing with the particular foods encountered in their ancestral environment. Similarly, from an evolutionary perspective, the human brain/mind can be expected to comprise numerous, specific, complex mechanisms that evolved in response to ancestral environmental conditions, rather than simple, general processes of association and symbol manipulation" (Crawford & Anderson, 1989, p. 1454). By attempting to understand ancestral environmental conditions, then, we may gain clues to the nature of human cognitive mechanisms.

Evolutionary biology has also influenced theories of cognitive development, as we have seen with Piaget's theory in Chapter 6. Piaget believed that children's transitions from stage to stage in development resulted in ever more adaptive modes of thinking and reasoning. In this way, he conceived of cognitive development as a process paralleling evolutionary change. Evolutionary concepts, then, served for Piaget as a framework for understanding cognitive development.

Others have suggested that Piaget's genetic epistemology may inform evolutionary biology. For example, the reasons for organisms developing the particular forms they do cannot be attributed solely to genetic factors adapting to particular environments. Certainly that does occur, just as children develop operative schemes adapted to their environments. But children also "spontaneously create new schemes of behavior for which appropriate environments are then realized if possible" (Goodwin, 1985, p. 53). In Chapter 6, the example was given of children actively seeking conditions under which to apply some new understanding. Translated into biological terms, this suggests that "spontaneous reorganization within the hereditary constraints can occur, producing organisms with new morphologies and behavior patterns which must then either discover or create appropriate environments" (Goodwin, 1985, p. 54).

This view of evolution has been hailed as insightful but also limited. It draws attention to an overlap in developmental and biological theories in that both attempt to explain the capacity of organisms to internalize aspects of their environment. But the disregard for the impact of social structures on human development is considered a serious oversight (Scaife, 1985), a sentiment in obvious agreement with the theoretical positions of Bruner and Vygotsky that were discussed in Chapter 7.

Implications of Evolutionary Psychology for Learning and Instruction

What conclusions can we draw from sociobiology that might inform our study of learning? One, undoubtedly, is that our genetic, evolutionary heritage imposes certain constraints on learning, or determines predispositions to learn certain things in certain ways. Another, however, is that "predispositions and constraints are outcomes, not causes" (Timberlake & Lucas, 1989, p. 260). In other words, what is actually learned and exhibited depends as much on particular environmental stimuli as it does on genetic history. Let us examine these two conclusions more closely.

The role of evolutionary factors in conditioning suggests a more careful analysis of current behavior, desired behavior, and possible reinforcers in light of potential learning predispositions. For example, if humans are predisposed to fear snakes and spiders, such phobias, once acquired, may be extremely resistant to extinction (Lohordo & Droungas, 1989). A program designed to teach people to overcome their fears may therefore be ineffective if it relies solely on cognitive, informational factors (e.g., "Spiders are good because they eat other insects"). A learner might agree with such statements intellectually, but find that instinctive reactions prevail when a spider is encountered. Systematic desensitization programs, on the other hand, provide continued and increasing exposure to the feared object in such a way that instinctive reactions can be overcome.

In behavioral interventions, the type of reinforcer chosen may influence the degree to which desired behavior is learned. Breland and Breland (1961) hypothesized that their food reward elicited species-specific feeding patterns that interfered with the animals' acquisition of the desired operant behavior. It is possible that the overuse of primary reinforcers with humans would have a similar effect. Finally, behaviors that are most similar to what proved adaptive in ancestral populations are likely to be the easiest to condition (Timberlake & Lucas, 1989). Likewise, behaviors for which no predisposition to learn has developed are likely to be more difficult to establish. As an example, these might include reactions to people who are different from ourselves. In early human societies, strangers were commonly feared and excluded from participation within the group. However, today's global and multicultural society requires that different races learn to live in harmony. For this to occur, cooperative behaviors must be strengthened with sufficient practice and training to become dominant over more instinctual behaviors (Garcia, Brett, & Rusiniak, 1989).

That current environmental conditions are important to the expression of evolutionary predispositions is the primary thesis of Crawford and Anderson (1989). They argued against the notion that traits with evolutionary significance must necessarily appear in all individuals. Similarly, they argued against the idea that all current behavior must be adaptive. Instead, they suggested that evolutionary traits and ecological conditions interact to produce behavior. Moreover, environmental conditions can exert an influence either at the time a behavior is exhibited or during the individual's development.

To understand how these interactions may operate, consider the following examples described by Crawford and Anderson (1989). Three mating tactics can be observed in male scorpionflies: (1) presenting a dead insect to the female as a nuptial gift, (2) generating a salivary mass to offer as a nuptial gift, or (3) forcing copulation without a nuptial gift. Which tactic is followed depends solely on current environmental conditions, namely, how many males are competing for the limited number of females and how abundant are the insects offered as nuptial gifts. When there are few females and many males, for example, forced copulation is the observed tactic. When the numbers are reversed, however, and plenty of insects are available, the male scorpionfly is most likely to offer an insect as a nuptial gift.

Looking at the reproductive tactics of humans reveals an analogous example, except that the tactic pursued later in life appears to depend upon circumstances experienced in childhood. That is,

> The child whose father is not involved in the family is 'being prepared' for life in a society where males frequently compete for access to a number of females and do not form enduring bonds or provide much investment in their offspring. The child whose father is deeply involved in the family, on the other hand, is developing attributes enabling it to maximize its reproductive success in a society where males form long-lasting relationships with a single female and provide a high level of investment in their offspring. (Crawford & Anderson, 1989, p. 1452)

Thus, whereas genes may control the mechanisms that produce behavioral differences (e.g., three, and only these three, mating patterns are passed on through generations of scorpionflies), environmental and developmental interactions determine which behavior is learned and manifested.

Unraveling the relationship between genetic histories and environmental contingencies is no easy task, especially in humans. For obvious reasons, the study of twins, particularly those reared apart, offers the best hope. Crawford and Anderson (1989) suggested that groups of identical twin pairs be studied on the basis of known genetic differences. Moreover, they recommended a focus on behaviors closely related to reproductive function and sensitive to environmental conditions in a way that would have contributed to fitness in an ancestral population. Similarly, examination of dominance hierarchies and social organizations of groups may prove fruitful for understanding sociobiological influences (Bernhard, 1988). From a single pair of twins, then, as described in the Twins scenario, we can reach no firm conclusions about the relative impact of genetic history versus environmental conditions on learning. Yet, the striking similarities seen among twins reared apart perhaps precludes an extreme environmentalist interpretation.

Finally, it is important to realize that the human environment has changed dramatically in recent years. This leads to the possibility that previously adaptive behavior may be no longer adaptive or socially acceptable (Crawford & Anderson, 1989). Behaviors related to sexual competition among men for women, for example, probably correlated highly with reproductive fitness in ancestral populations. Today, however, they are more likely to be viewed as sexist. Similarly, behaviors that could have reduced fitness thousands of generations ago may now be culturally accepted or even desirable. The adoption of unrelated children is a possible example. In either case, such behaviors may present problems for learning. No matter what our training, we may occasionally respond negatively to situations once associated with reduced fitness. In the same way, we may find it difficult to eliminate completely ways of thinking, speaking, or acting that have been favored by natural selection in the distant past.

In schools, one impact of a rapidly changing environment has been the neglect of children's biologically based needs for belonging to and working within a group (Bernhard, 1988). Even in cooperative learning structures, individual achievement and individual accountability are stressed (Slavin, 1991). Yet, in early human societies, "effective defense against predators and the hunting of game were both necessarily cooperative ventures" (Sagan, 1977, p. 104). And "reciprocity in a foraging band [was] ensured by a variety of relationships and conventions that tie[d] individuals together and motivate[d] cooperation. No such relations or traditions exist in the school, except in the most attenuated and abstracted forms" (Bernhard, 1988, pp. 121–122).

What this view suggests for instruction, then, is a greater emphasis on cooperation in learning, which supports the views of Bruner and Vygotsky that were discussed in the previous chapter. Perhaps what a sociobiological perspective adds to the picture thus far created is an emphasis on extended experiences in groups, where students work within the same group for a long time. In that way, children must work out their social differences and develop cooperative behaviors that enable them to reach their goal. Bernhard (1988) argued for multi-age groups, as well, because mixed-age groupings occurred naturally in foraging societies and occur naturally in today's adult society. Younger children can learn much from observing and imitating their older peers, and older children gain valuable information about parenting when they interact with younger children (Bernhard, 1988).

Summarized in Table 8.1 are principles for learning that may be derived from an evolutionary perspective and their potential implications for instruction.

TABLE 8.1 ***Implications of Sociobiology for Learning and Instruction***

Principle	*Implication for Instruction*
1. Humans may be predisposed to certain fears.	Programs designed to teach people to overcome their fears are likely to be most effective when they include systematic desensitization.
2. Behaviors for which there is no predisposition to learn (e.g., that were either not required or not adaptive for ancestral populations) may be difficult to establish.	Extensive time and practice should be built into teaching programs for these behaviors. For example, computers are an artifact of current culture, so that humans may require extensive practice to become skilled in their use.
3. Previously adaptive behavior, which is no longer useful in today's society, may be difficult to overcome.	Time and practice are again key variables for effective instruction when these behaviors are inadvertently triggered. For example, learners in cooperative learning groups may initially experience difficulty working together, because they must work out their differences and establish appropriate social bonds.
4. Actions once associated with decreased fitness in ancestral populations may be difficult to establish.	Attitude learning is at issue here, because learners must be convinced that these actions are now desirable in the context of today's society. For example, learning to work cooperatively with other races may be a matter of perceiving and valuing a common goal.

Proximate Causes: Neurophysiology of Learning

"One of the great scientific questions of our day is: How is information acquired and stored in the brain?" (Martinez & Kesner, 1991, p. xv). As in sociobiology, no easy answers to this question are forthcoming. Consider the very difficulty of the task. The human brain has some 12 billion neurons and 5000 synapses, all linked together in incredible complexity (Bower & Hilgard, 1981). Moreover, most studies of the brain are aimed at understanding what enables information storage. This means that the physiology of receptors (i.e., our sensory systems for vision, hearing, smell, taste, and feeling) and the physiology of effectors (i.e., different muscle systems) are not considered relevant to study. Even without taking these systems into account, understanding the neurobiology of the brain and its relation to memory and cognition is a formidable enterprise.

Despite the difficulties inherent in studying the brain, neuroscientists have made remarkable progress in understanding its structures and functions. From early beliefs that specific memories and cognitive functions must be located in particular regions of the brain, views about information storage have evolved to implicate brain systems regulating storage and the capacity for storage. In addition, most neuroscience evidence is used together with cognitive analyses in drawing conclusions about the brain and learning (cf. Schacter, 1992). Let us look further at how these views have evolved, as well as the evidence for prevailing views. In addition, brain systems as they relate to processes of attention, cognitive development, and knowledge representation are discussed.

An Overview of Neural Architecture Implicated in Learning

Perhaps the best way to begin is with a review of the neural architecture of learning and memory as we currently know it. Pictured in Figure 8.3 is a right side view of the human brain, showing the lobes of the cerebral cortex, the cerebellum, and part of the brain stem. The line labeled *hippocampus* points from the general location of the organ. Since it is found on the medial area (or inside) of the temporal lobe, it would not actually be seen from this view.

Which structures in the brain have been specifically implicated in learning? First, the frontal lobe appears to be associated primarily with attention, specifically, the ability to pay attention on cue. The left frontal lobe is also the site of what is known as Broca's area, which seems to be responsible for our ability to speak. The parietal lobe has been associated with the organizing aspects of attention, that is, the ability to attend to specific differences in stimulation, such as different letters in reading. The parietal lobe also seems to be involved in procedural memory, or being able to carry out procedural tasks.

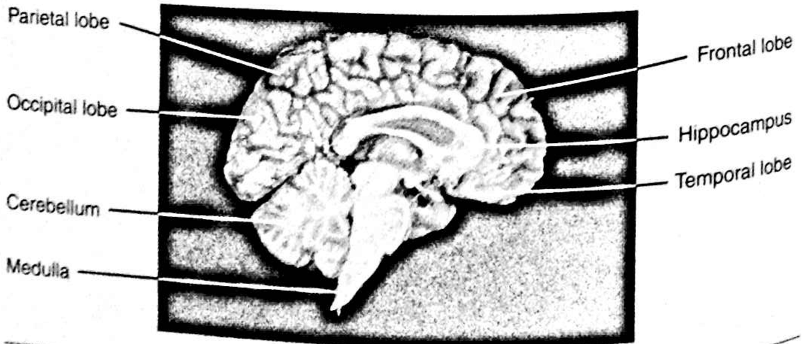


FIGURE 8.3 *A Right Side View of the Human Brain*

The hippocampus plays perhaps the largest role in learning and memory. On one hand, it appears to be involved in our ability to selectively allocate attention and orient us to sudden events which demand attention. In this role, the hippocampus appears to be aided by subcortical mechanisms, probably from the thalamus (in the brain stem structure). A second function of the hippocampus, however, seems to be as mediator of declarative learning, or knowledge of facts and concepts. It is also likely that this role involves organizing memory traces made up of cell assemblies in many areas of the brain. Finally, the left hemisphere (the unseen side of Figure 8.3) is implicated in language and analytic functions, whereas the right hemisphere (shown in Figure 8.3) is implicated in visual-spatial functions.

What is not obvious in the diagram, of course, is that each brain structure is made up of millions of neurons and thousands of synapses. Strong evidence suggests that number alone, however, cannot fully explain human intelligence (Gazzaniga, 1995). Development causes a differentiation of neurons and synaptic changes. But learning, as well, appears to result in new dendrites and many new temporary synapses (at least in the hippocampus [Rosenzweig, 1986]), some of which remain as stable modifications to the neural architecture. Finally, hormones and neurotransmitters (substances that permit communication between neurons) are certainly involved in memory formation and modulation, but their roles are far from being fully understood.

Let us now consider the evidence for how the brain is involved in learning and memory.

Cerebral Localization and the Search for the Engram

Our intuitive beliefs about the brain as the seat of memory and mind have a long and distinguished history. Early Greek philosophers, including Pythagoras and Plato, subscribed to this view. Medieval physicians, long influenced by the medical pronouncements of Galen in the second century A.D., believed that different parts of the brain were each responsible for different psychological functions. Even Descartes, the father of mind-body dualism, located memories in the brain and not the soul. With the work of Franz Joseph Gall (1758–1828), however, came extended efforts to locate mental faculties in the specific areas of the brain thought to be responsible for them.

Gall was a neuroanatomist who located more than thirty psychological functions in distinct organs of the brain. He assumed that the degree to which certain cerebral parts were developed would be manifested not only in behavior but in the form of the head. Thus, the propensity to steal, for example, corresponded with a well-developed "organ of cunning," which was apparent in a long prominence on the skull of thieves (Gall, cited in Herrnstein & Boring, 1968).

Although Gall's phrenology captured the imagination of the populace at the time, it was not held in high regard by his scientific colleagues. One of his harshest critics, an experimental physiologist named Jean Marie Flourens (1794–1867), conducted studies to prove that the brain's functions are distributed throughout rather than localized to a specific region. Flourens removed (ablated) or destroyed (lesioned) parts of animals' brains and observed the behavior changes that resulted. Instead of losing specific abilities or cognitive functions, as phrenology predicted, animals simply became more stupid overall as more of their brain was removed.

Despite Flourens's evidence for a distributionist view of brain function, scientists continued to find appealing the idea of localized centers for brain activity. In 1861, Paul Broca published the clinical findings of a patient who suffered from loss of articulate speech. After the patient's death, an autopsy of his brain revealed lesions in the left front neocortex. Broca argued that this region of the brain, subsequently known as Broca's area, must be responsible for the observed aphasia. A few years later, two German physiologists, Fritsch and Hitzig, conducted a series of studies in which they were able to produce eye movements in a patient by stimulating certain areas of the cerebral cortex (Herrnstein & Boring, 1968). Their findings, together with those of Broca, suggested that the brain does possess some specialized areas for certain functions. Whether specific memories could be traced to regions of the brain, however, was still an open question.

In the early 1900s, while still a graduate student working with John B. Watson, Karl Lashley began the search for the engram, or trace in the brain storing a particular memory. "One has the feeling that then and throughout his life, Lashley wanted to believe in localization of the memory trace, but his own results kept confounding his belief" (Donegan & Thompson, 1991, p. 8). In a series of investigations, Lashley and Franz (1917) had rats learn mazes and systematically ablated or lesioned varying amounts of their frontal cortex before or after learning. Their results forced Lashley to conclude, in his classic 1929 monograph, that memory traces are stored in the cerebral cortex but that they are not localized.

In Lashley's studies, the rats appeared to gradually lose their ability to learn or remember a maze as more and more of their brains was removed or destroyed. But loss in learning ability or memory did not occur as a function of the site of brain tissue destruction. Lashley's results, then, were consistent with those of Flourens, providing additional evidence to support a distributionist view of the brain.

If we accept the proposal that learning and memory are activities of the whole brain, then how are we to account for the findings of Broca, Fritsch, and Hitzig mentioned earlier? At least one answer can be found in the lesion approach to localization adopted by Flourens, Lashley, and others. Given the delicate and complex nature of the brain, it is likely that the destruction of one part will have widespread effects, not confined to a single memory. "It is, in the words of Pavlov, as if one struck a delicate machine with a sledge hammer and then studied the results" (Brogden & Gantt, 1942; cited in Donegan & Thompson, 1991, p. 9).

More modern approaches to localization now include electrical stimulation to parts of the brain, as well as intracranial injections of drugs to block or activate particular neurotransmitter-receptor systems. Although these techniques are admittedly less invasive than removal or destruction of brain tissue, they, too, typically affect more than a single cell or anatomical location in the brain. As a result, for progress to be made in understanding the neural substrates of learning and memory, the problem of localization had to be conceptualized with alternate assumptions. Donald Hebb, a former student of Lashley's, provided the insight when he proposed the concept of cell assembly (Donegan & Thompson, 1991).

According to Hebb, memories are not represented by a single neuron, but by a network of neurons—the cell assembly—in the cerebral cortex. Moreover, these neurons are thought to be distributed and able to participate in more than one memory. This means that a given memory is localized in the sense of it being represented by a particular cell assembly, but it cannot be anatomically located since the neurons making up the assembly are distributed throughout the cortex. Notice the similarity between the cell assembly and the model of memory proposed by the parallel distributed processing theorists (see Chapter 3). They, too, argued that networks of subsymbolic units participated in processing and memory. Hebb's theory not only had the effect of renewing interest on the part of researchers in analyzing neurological substrates of learning and memory in the brain, but also demonstrated that understanding how memories are represented in the brain is no easy or simple matter.

Hebb's concept of the cell assembly remains "the best currently accepted idea about how information is stored in the nervous system" (White & Salinas, 1998). However, questions about localization of memory have changed, to the point where researchers are even questioning the value of attempting to correlate structure with function in the brain (Sarter, Berntson, & Cacioppo, 1996).

In the past few years, advances in the technology of brain imaging have offered researchers an entirely noninvasive means of studying cognitive processing. In most imaging studies, subjects are presented two tasks that are presumed to differ only in the cognitive operations they require. The brain images from the control task are subtracted from those of the experimental task, and the resulting image is assumed to reflect the portion of the brain that was uniquely stimulated by the experimental task. According to Sarter et al. (1996), "Imaging studies have become a major force in national neuroscience policy and have emerged as a basis for the definition of programmatic research goals" (p. 14) despite "the [questionable] manner in which many inferences are drawn about the cognitive significance of localized brain activity" (p. 17). They provided analyses illustrating that areas activated in a brain image may or may not contribute meaningfully to a cognitive process. Likewise, they argued that a brain area should not be excluded as potentially relevant simply because it was not activated in a brain image.

It appears that complex and distributed systems of neurons are implicated in learning, with some systems centrally involved with the development and representation of a memory trace and others peripherally involved in the expression of a learned behavior (cf. Donegan & Thompson, 1991). Questions that remain to be answered concern just what neuronal systems change with certain types of learning and by what mechanisms they change. These are general questions that can now be examined more closely in the context of learning processes that concern educators.

Attention and the Brain

Cognitive researchers have long recognized the importance of attention in learning. For information to be processed for permanent storage in memory, it must first be noticed. Moreover, learners selectively attend to certain aspects of stimulation that pertain to their learning goals, that are novel and require additional processing resources, or that are distinctive and unconsciously attract notice. Finally, skills that are well learned and practiced typically require less attention of learners, freeing them to allocate attentional capacity to related, higher-level tasks. In reading, for example, decoding of letters and words is more or less automatic as learners concentrate their attention on comprehending the meaning of what is read. (See Chapter 3 for an extended discussion of attention.)

Given the importance of attention, what unique contributions may a neurological perspective offer to our overall understanding of the phenomenon? What brain systems underlie attention? What investigations of these systems have been conducted and to what new insights have the investigations led? Many different aspects of attention have been studied, and myriad results make difficult any theoretical synthesis. Moreover, many scholars include attention as one of many mechanisms to be accounted for in a systems view of memory (e.g., Johnson & Chalfonte, 1994). Nonetheless, they do agree that attention, however investigated or conceptualized, involves selectivity.

Characterizing attention as a state, a resource, or a process provides a useful framework for discussing and evaluating results of studies on attention. All three concepts involve selectivity. Attention as a state occurs when a learner maintains an attitude of expectation, alert to information and heedless of distractions. This is characteristic of learners who are interested in what they study. By contrast, learners who are bored or suffer from an attention deficit disorder are easily distracted from a learning task.

Attention as a resource refers to a learner's capability of selectively allocating more attention to one of several simultaneously occurring events. Although this is often done quite unconsciously, as in driving a car while attending to a program on the radio, it may also occur quite deliberately, as in listening to one conversation at a party while ignoring all others.

Finally, attention as a process involves selecting particular information for further analysis and interpretation over other, available information. For example, a high school clarinetist who attends a local symphony performance is likely to selectively process the overall sound of the orchestra for the specific notes of the clarinet. More than the average person, the clarinetist may hear any sour notes this section of the orchestra plays during the performance.

These three aspects of selective attention have been investigated for their neurological substrates in the brain. Studies have typically focused on identifying what parts of the brain and what mechanisms within the brain are responsible for attention. In some studies, the effects of lesions are investigated. In others, electrical signals from the brain, as well as eye movements, are recorded and monitored as attention is systematically varied. Let us now look at the specific evidence related to the state, resource, and process aspects of attention.

Controlling Attentional States. The ability to sustain attention and adapt attention to changing task demands has been extensively studied in patients with varying degrees of brain damage. Lack of attentional control and inattention have been observed frequently among patients with frontal lobe damage (Picton, Stuss, & Marshall, 1986). In one case, for example, a man with damage to the left frontal lobe had difficulty concentrating on various counting tasks. He was able to count by 3s, but "on subtracting serial 7s, which was completed after counting by 3s, he was unable to stop himself from subtracting (correctly) by 3s. He verbalized that he should subtract by 7s, and yet said, 'Here I go with 3s again'" (Picton et al., 1986, p. 24). This patient simply could not control his attention when multiple tasks required a shift in attention from one task to another.

The syndrome of inattention refers to the failure of a patient to respond to stimuli when such stimuli are presented on the side opposite a cerebral lesion. Thus, individuals fail to attend at all to a task rather than experience difficulty controlling their attention between tasks. This apparently occurs most often with lesions in the right parietal lobe, but has also been reported with lesions to the frontal lobe and elsewhere (Damasio, Damasio, & Chang Chui, 1980; Picton et al., 1986). Recent evidence continues to support the dominance of the right hemisphere in maintaining alertness (e.g., Ladavas et al., 1994).

Two attentional disorders for which no specific pathological findings have been identified are schizophrenia and hyperactivity. In both disorders, behavioral symptoms resemble those of patients with frontal lobe damage, causing researchers to speculate that the frontal lobe is in some way involved. One reasonable hypothesis is that, for hyperactive children, maturation of the frontal lobe has been delayed (Stamm & Kreder, 1979). Equally probable, however, is the possibility that attention problems in hyperactive children and schizophrenics are caused by disruptions in catecholamine metabolism.

Catecholamines are neurotransmitters, substances that influence or modulate the electrical activity of neurons. Increased or decreased levels of the cerebral catecholamines appear to result in attentional disorders. In hyperactivity, a depletion of catecholamines is assumed, because the attention deficit symptoms can be successfully treated with amphetamines or amphetamine-like drugs, which increase the release of catecholamines (cf. Margolin, 1978). Take note, however, that people whose catecholamine levels are normal should experience increased attentional problems with administration of amphetamines, because of abnormally increased catecholamine levels. Similarly, an excess of catecholamines in schizophrenics is assumed, because drugs that block the reception of catecholamines by cerebral neurons are effectively used for treatment (Carlsson, 1978).

Unfortunately, not enough is known about the long-term effects of drug treatments to reach firm conclusions about the role of catecholamines in attention. "The prolonged changes in transmitter concentration brought about by chronic drug administration may alter the sensitivity of the receptors and the metabolism of the transmitter" (Picton et al., 1986, p. 38). In other words, over time drugs may significantly change brain metabolism in ways that we cannot yet predict. It is for this reason that other means besides drugs are often chosen in the treatment of hyperactive children.

Finally, results of studies using electroencephalograms to record electrical activity in the brain support the general conclusion that both the frontal lobe and cerebral catecholamines are involved in controlling attention. In typical electroencephalographic studies, brain waves are recorded over a period of time in which subjects selectively attend to different stimuli. One measure of attention is the difference in wave amplitude between what is evoked by a stimulus when it is ignored and when it is attended to. This has been termed *processing negativity* (Hansen & Hillyard, 1980).

When the brain wave patterns of patients with frontal lobe damage are compared with those of normal subjects for selective attention tasks, their processing negativities are smaller. The same is true for children with hyperactivity, who also show a decreased amplitude of a particular wave known as P3. Drug treatment has been shown to increase the P3 amplitude in hyperactive children, as well as their processing negativities (Picton et al., 1986). From these results, then, it seems likely that the frontal lobe and cerebral neurotransmitters play a critical role in an individual's ability to control his or her attentional state.

Selectively Allocating Attentional Resources. Attention as a matter of allocating resources obviously depends upon the concept of capacity. As we have seen from Chapter 3, conceiving of attention in terms of capacity is perhaps the predominant approach currently taken by cognitive theorists. But there is support for this conception from the biological perspective as well. On the one hand, our apparently limited capacity for attention may be viewed as an evolutionary adaptation (Simon, 1986). That is, without some kind of limitation, we would be disposed to processing so many irrelevancies from the wealth of stimulation surrounding us that goal-directed behavior might be impossible. This was the case for a Russian man whose photographic memory produced a flood of remembrances with every interaction, rendering him incapable of living a normal life (Heminway & Tegriti, 1984).

On the other hand, discovering just what biological mechanisms govern attentional limitations may assist us in determining how to make the most of the capacity we have. Until recently, it has been difficult to separate attentional capacity from processing strategy, because both influence overall processing efficiency (Gazzaniga, 1984). However, neurological evidence now points to a subcortical mechanism governing the allocation of attention, rather than the cortical mechanisms already implicated in the control of attentional states.

In one study, Holtzman and Gazzaniga (cited in Gazzaniga, 1984) presented subjects with 3 × 3 matrices and the task to detect the location of several *x*s. These matrices, sometimes the same and sometimes different, were simultaneously presented to both sides of the visual field while subjects fixated on a point between them. Subjects with normal brains could not do the task, but patients whose brains were hemispherically disconnected could do it easily, in effect processing more stimuli at once than is possible for a normal person. Normal brains, then, are limited in attentional capacity that can be allocated to processing stimuli.

Additional studies revealed interactions between the hemispheres in attentional allocation, which suggests a subcortical rather than cortical mechanism at work. That is, if attentional resources are allocated cortically, the hemispheres should operate independently of one another. What Holtzman and Gazzaniga (1982) found, however, was that working on a hard problem in one hemisphere diminished the attention by the other hemisphere on a concurrent task. Similarly, subjects with separated hemispheres could scan bilateral arrays twice as fast as unilateral arrays, indicating that the hemispheres scanned independently. Normal subjects, on the other hand, performed the same on both arrays, indicating that the intact corpus callosum was responsible for maintaining a focused attention (Luck et al., 1994; see also Kingstone et al., 1995).

Finally, there is evidence that cortical processes, in particular the hippocampus, also influence attention allocation. Animals with hippocampal lesions fail to orient as quickly to novel stimuli introduced into their environments. The orienting response is thought to be a critical means of adapting to the environment, because it enables an organism to suppress ongoing behavioral activity in order to respond to a sudden change in real-time requirements. As Simon (1986) put it, "Because bricks do fly through the air sometimes, it is good to be able to notice and dodge a brick even if you are not scanning the horizon for missiles when it comes flying" (p. 106).

Selectively Organizing Attention. When learners not only allocate attentional resources to a particular task, but also then direct those resources to selectively process certain information, they are organizing their attention. This is an important concept for learning, because readers must attend to differences among letters to competently decode words. Orchestral performers must attend to differences among sounds to be sure they are playing in tune. Wine tasters must attend to subtle differences in flavor and bouquet to rate quality of wines. Attentional differences of this sort have been studied primarily in terms of evoked potentials in human brain wave activity, eye movements, and a variety of cognitive measures (such as response times to pattern-recognition tasks).

To begin with, promising results have emerged from studies evaluating event-related potentials of children with learning disabilities. Typically, certain types of learning problems, which relate in some way to attention patterns, are diagnosed in children through behavioral techniques. Dyslexic children, for example, may experience difficulty attending differentially to similar letters, such as *b* and *d*. The brain wave patterns of these children are then compared with those of normal children to discover systematic differences that might distinguish between the two groups (cf. Duffy, Burchfiel, & Lombroso, 1979). In addition, children with diagnosed differences in learning abilities may be given specific cognitive tasks and their brain patterns observed while they complete the tasks.

Brain activity mapping has been shown to discriminate between normal and dyslexic children (Duffy, Denckla, Bartels, & Sandini, 1980; Duffy, Denckla, Bartels, Sandini, & Kiessling, 1980; Torello & Duffy, 1985), and among gifted learning disabled, gifted normal, normally achieving, and learning disabled students (Languis, Bireley, & Williamson, 1990; Languis, Miller, & Bertolone, 1990). In the latter study, gifted learning disabled learners were defined as those who score very high on measures of intelligence, such as the Wechsler Intelligence Scale for Children, Revised (*WISC-R*), but who display a discrepancy between their verbal and performance IQ subscores. In general, gifted children demonstrated greater overall activity in brain patterns than their nongifted counterparts, but the gifted learning disabled students also showed some of the same specific patterns as nongifted learning disabled students.

Despite the apparent success of brain mapping in detecting neurological differences between learning disabled and normal children, caution is recommended in the use and interpretation of the technique (cf. Picton et al., 1986). Although the brain patterns of dyslexic children, for example, may indicate abnormalities in the area of the brain important for speech and language, they may also be symptomatic of boredom or drowsiness. Overall, the results of brain mapping studies can be very difficult to interpret. Sometimes, anomalous patterns appear on electroencephalograms that have no clinical significance. Additionally, similar brain patterns may be observed among individuals that cannot be interpreted along a meaningful dimension. In spite of these difficulties, researchers are hopeful that brain patterns may prove useful both in diagnosing learning problems and in finding appropriate interventions for those problems.

Along with brain mapping, researchers have used eye movements to study the organization of attention. This work stems from a basic assumption that orienting of attention plays a critical role in visual processing. It seems obvious that items are more likely to be recognized and processed appropriately within the focus of attention than outside it. Moreover, this focus is extremely limited because only the fovea is capable of detailed pattern vision. In reading, for example, learners can perceive about ten items to the right and three to four items to the left of their fixation point (Rayner, Well, & Pollatsek, 1980). Thus, eye movements represent an important indicator of attentional orienting and subsequent processing.

There is also evidence, however, that a covert attentional mechanism, linked to neural systems in the parietal lobe, operates independently of the eye movement system. Posner and Friedrich (1986) described a study by Chang (1981) that most clearly illustrates this mechanism. Chang presented stories in such a way that subjects could read the words while maintaining a point of fixation. This procedure should eliminate any right-left asymmetry in reading if such asymmetry is a function of the eye-movement system. Chang found instead that bias in the visual field remained, and it reflected the internal scan of the words. That is, when words were presented normally, subjects had a larger visual field to the right of fixation. When words were presented upside down, subjects had a larger visual field to the left of fixation. Posner and Friedrich (1986) took these results to mean that attention was covertly driven by some internal semantic operation.

The influence of semantic codes on attention has also been documented by so-called priming studies. When learners are presented with a word from a particular category, their recognition of other words from the same category is facilitated. This effect occurs regardless of the modalities in which the words are presented. That is, both spoken and written words facilitated subjects' recognition of other spoken or written words. Posner and his colleagues contend, therefore, that learners represent meaning in a single semantic code which can be accessed through different sensory pathways (cf. Posner, 1984; Posner & Friedrich, 1986; Sen & Posner, 1979). Assuming this to be true, an important question arises. That is, to what extent do specific intentional strategies influence the ability to shift attention from one kind of code to another in order to accomplish a specific task?

It appears that learners commonly shift attention among different sensory codes, depending upon the nature of the task in which they are engaged, as well as their own abilities and preferences. Beginning spellers, for example, typically rely on phonological codes whereas beginning readers make use of mostly visual codes. With experience, able learners become efficient in coordinating information from several codes and flexible in shifting attention among codes to suit task demands. It is also true, however, that some learners prefer particular codes and may rely on one kind of information when they might better focus on an alternate kind. Good proofreading, for example, probably depends on the ability to isolate and use visual information, to the exclusion of phonological information.

So what should we make of this evidence regarding the organization of attention? As with other aspects of attention, the cerebral cortex is implicated as the neurological basis, but precisely what systems operate and how they operate in attentional organization are not yet fully known. Simon (1986) noted that Posner's discovery of covert attention should call into question the use of eye movements as a primary indicator of attention. Posner (and Friedrich, 1986) suggested that it is too early to make firm prescriptions for instruction from the current neurological evidence on attention. Employing multiple codes during instruction is likely to facilitate learning. But it is not yet clear whether curricula should emphasize one type of code over another or attempt to match learner coding preferences to materials relying upon those preferences. A third alternative is to provide learners with experiences in many types of codes in order to develop their skills in nonpreferred modes. This latter suggestion is consistent with implications of dual-code theory as well as educational semiotics (see Chapters 3 and 5).

The fact that attention is not a unitary construct offers an additional implication for instruction. One should probably not assume that a particular instructional technique "commands students' attention" and is therefore sufficient to assure learning (Schunk, 2004). Rather, it is likely that multiple techniques are necessary to alert learners, help them allocate their attention appropriately during learning, and focus their attention on relevant aspects of the task so as to optimize processing.

Learning, Memory, and the Brain

In the search for the engram, early biological researchers primarily examined one aspect of learning and memory, namely, information storage. To some degree, these researchers also tackled the twofold question of how memories are acquired in the first place and how acquired knowledge is used. Donegan and Thompson (1991), for example, suggested two separate systems as responsible for one, acquisition and storage, and two, performance (or use). More recently, interest in multiple memory systems has expanded rapidly, with a "growing number of cognitive and behavioral neuroscientists [advancing] increasingly detailed hypotheses concerning the nature of and relations among different memory systems" (Schacter & Tulving, 1994).

Efforts to understand the biology of learning and memory have proceeded simultaneously on many fronts, from studies with invertebrate animals to studies with both normal and brain-damaged humans (Martinez & Kesner, 1998). Various approaches to the problem have also been undertaken, including cognitive, neuropsychological, neurobiological, and computational (Schacter & Tulving, 1994). It is an exciting time for researchers in this field, and only an overview of current developments can be presented here. The nature and variety of memory systems that have been proposed is considered first. Then, because "language is a paradigm case for understanding how humans represent, acquire, and use a complex cognitive system" (Gleitman, 1986, p. 119), the biological substrates of language acquisition are discussed.

Types of Memory Systems. The impetus for distinguishing types of memory came initially from attempts to explain global anterograde amnesia (Mishkin, Malamut, & Bachevalier, 1984). With this type of amnesia, patients suffer memory loss but can retain new experiences of a certain type. They can, for instance, acquire the skills necessary to trace mirror images of words but then cannot later recall what the words were that they traced. Characterizing the lost versus spared abilities of these patients, researchers have used the labels "recognition versus associative memory…episodic versus semantic memory …working versus reference memory…vertical versus horizontal associative memory…declarative versus procedural knowledge…elaborative versus integrative processing…, and automatic versus effortful encoding" (Mishkin et al., 1984, p. 65).

The plethora of concepts proposed to distinguish a multiple-memory-systems view from a unitary-memory view led to enough confusion in the literature that Schacter and Tulving (1994) proposed criteria for defining memory systems. They wrote, "Memory systems are not forms of memory or memory processes or memory tasks or expressions of memory" (p. 11). Rather, "a memory system is defined in terms of its brain mechanisms, the kind of information it processes, and the principles of its operation" (p. 13).

Reviewing current research on human learning and memory also led Schacter and Tulving to suggest a classification of memory systems, depicted in Table 8.2. (Note the similarities in this classification with the types of memory proposed and investigated by cognitive information-processing researchers in Chapter 3.) Subsystems may also be distinguished from systems by the different kinds of information they are presumed to process. For

TABLE 8.2 *Major Systems of Human Learning and Memory*

System	*Other Terms*	*Subsystems*	*Retrieval*
Procedural	Nondeclarative	Motor skills Cognitive skills Simple conditioning Simple associative learning	Implicit
Perceptual representation (PRS)	Nondeclarative	Visual word form Auditory word form Structural description	Implicit
Semantic	Generic Factual Knowledge	Spatial Relational	Implicit
Primary	Working	Visual Auditory	Explicit
Episodic	Personal Autobiographical Event memory		Explicit

Source: From "What are the memory systems of 1994?" by D. L. Schacter & E. Tulving. In D. L. Schacter & E. Tulving (Eds.), *Memory Systems 1994*, Cambridge, MA: MIT Press, 1994.

example, procedural memory has been characterized as a performance system, and it is thought to be involved in learning both motor skills and cognitive skills (its subsystems).

The argument for a nondeclarative procedural system comes from studies conducted with amnesic patients, of which perhaps the most well known and extensively studied is H.M. In 1953, at the age of 27, H.M. underwent an operation to relieve epileptic seizures that had become uncontrollable. Although the operation successfully eliminated the seizures, it also unfortunately caused total anterograde amnesia. Thus, although his short-term memory is intact, H.M. can form no new memories (Squire, 1987).

What is interesting about H.M.'s abilities is that he, like other amnesiacs, could perform the mirror drawing task but never remember that he had done it or what the words were. Moreover, he was able to acquire the skills necessary to solve the Tower of Hanoi puzzle (Figure 8.4), but he could not remember any specific facts or experiences related to his performance.

H.M. displays impairment in declarative or cognitively oriented memory systems while his procedural system remains intact (Cohen & Squire, 1981; Cohen, 1984; Squire, 1983, 1986, 1994). It logically follows that the kind of brain damage sustained in amnesiacs—namely, to the medial temporal lobe—must mediate declarative but not procedural memory. Interestingly, research conducted with monkeys demonstrated the same sort of

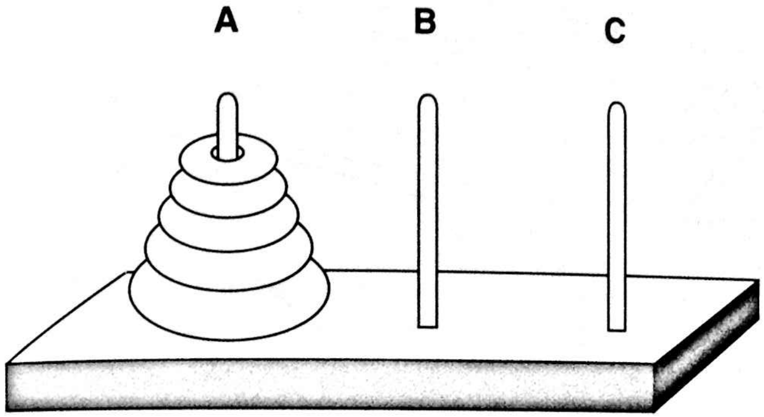


FIGURE 8.4 *The Tower of Hanoi Puzzle.* ***The goal is to transfer the rings from A to C without ever placing a larger ring on top of a smaller ring.***

performance pattern as observed in amnesic humans (e.g., Mishkin & Petri, 1984), providing additional evidence for the existence of a procedural memory system.

The other memory systems included in Table 8.2 relate to cognitive representation and storage, with working memory distinctive in the brevity with which it is able to retain information. Evidence of these systems comes from a variety of sources, and the neuroanatomical basis for some distinctions is still uncertain (Schacter & Tulving, 1994). Based upon their review of current findings, Squire and Knowlton (1995) proposed a taxonomy of memory systems that is shown in Figure 8.5. You can see that they distinguish primarily between declarative and nondeclarative systems but include most of the same subsystems as Schacter and Tulving (1994). Is one scheme more right than the other? Only time will tell. As Kesner (1998) put it, "Even though there are many similarities among the different neurobiological views of memory in terms of the proposed memory systems, there are important differences that should stimulate the development of new paradigms and further experimentation" (p. 405). It seems clear at least that the entire brain participates in learning and memory, but different brain systems contribute in different ways (Gershberg & Shimamura, 1998).

A Biological Basis for Language Learning. One approach to the neurophysiology of learning, as we have seen, is to study the capabilities of brain-damaged individuals, whether humans or other animals. The nature and location of the physical damage are then related to the types of impairments observed. Another approach, however, is to study a human capability that has an obvious and unquestioned biological component to it. Language

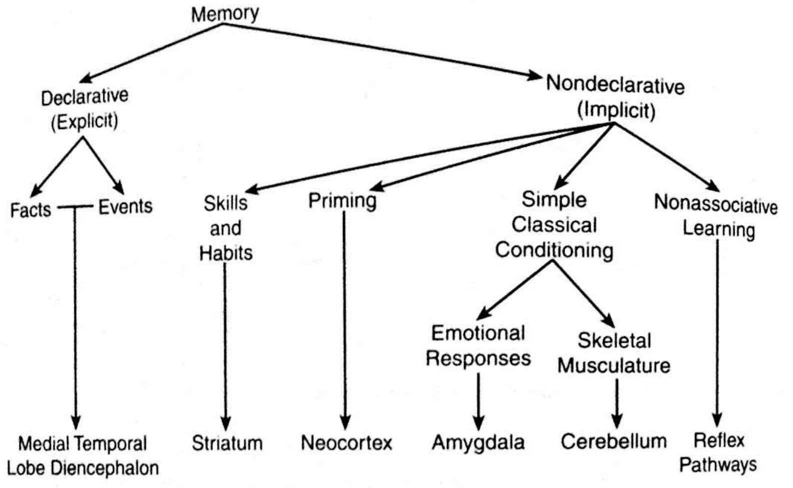


FIGURE 8.5 *A Taxonomy of Memory and Associated Brain Structures*

Source: From "Memory, hippocampus, and brain systems" by L. R. Squire and B. J. Knowlton. In M. S. Gazzaniga (Ed.), *The Cognitive Neurosciences 1995*, Cambridge, MA: MIT Press, 1994.

provides such a test case, because "to believe that special biological adaptations are a requirement, it is enough to notice that all children but none of the dogs and cats in the house acquire language" (Gleitman, 1986, p. 119).

The idea that language may be innate is not a new one. Leahey and Harris (1997) observed that Descartes assigned a special role to language as a vehicle for the expression of thought. In more modern times, however, Noam Chomsky (1965, 1972) has been largely responsible for promoting the view that language is an evolved, species-specific organ. Recall from Chapter 2 that behaviorists attempted to explain language as just another complex behavior, acquired through processes of operant conditioning. Chomsky was extremely critical of the behaviorist position and argued convincingly for a universal language faculty in humans. At the same time, Eric Lenneberg (1964, 1967) articulated a biological view of language acquisition. He pointed to clinical evidence that language functions are located in the left hemisphere, that language can neither be suppressed (e.g., deaf children will spontaneously invent sign language in the absence of verbal capabilities) nor language learning speeded up, and that certain forms of speech disorders are inheritable.

In the traditions of Chomsky and Lenneberg, Gleitman (1986) proffered three arguments as essential to a case for language being biologically preprogrammed. First is the fact that language learning proceeds uniformly within

a linguistic community despite tremendous differences in individuals' experiences. "Isolated words appear at about age 1 year, followed by two-word utterances at about age 2 years. Thereafter, sometime during the third year of life, there is a sudden spurt of vocabulary growth accompanied, coincidentally or not, by elaboration of the sentence structures. By about 4 years of age, the speaker sounds essentially adult" (Gleitman, 1986, pp. 121–122; cf. Lenneberg, 1967).

Second, children do not simply copy what they hear. They make systematic errors that suggest the use of an emerging grammar, of which the rules are never explicitly taught. For example, young speakers will systematically misplace auxiliary verbs in wh-questions, such as "What can I eat?" They will say instead, "What I can eat?"—a form that is never produced by older speakers or adults (cf. Bellugi, 1967; cited in Gleitman, 1986). Similar evidence comes from the order in which children acquire lexical categories. A child's first words are overwhelmingly nouns. Verbs appear slightly later, with adjectives and adverbs appearing still later (Gentner, 1982). These examples are difficult, perhaps impossible, to explain without reference to some sort of innate basis.

Finally, a third argument for the biological preprogramming of language lies in the mistakes that children do not make as they learn to speak. Gleitman provided an illustration with the following two sentences:

1. The man who is a fool is amusing.
2. The man is a fool who is amusing.

Now consider how these are transformed to yield yes/no questions:

1. Is the man who is a fool amusing?
2. Is the man a fool who is amusing?

Children apparently recognize that which *is* moves depends on the structure of the sentence, not the serial position of the word *is*. They never make the mistake of saying, "Is the man who a fool is amusing?" or "Is the man is a fool who amusing?" Yet it is extremely unlikely that children are ever taught the rather abstract rule, "It's the *is* in the higher clause that moves."

If we accept the premise, therefore, that biology plays a significant role in language learning, then we may proceed to the question of just what role it plays. From the studies conducted by Gleitman and others (cf. Feldman, Goldin-Meadow, & Gleitman, 1978; Newport, Gleitman, & Gleitman, 1977; also Fowler, 1986), she reaches the conclusion, first suggested by Lenneberg, that language acquisition is maturationally driven. The progress of normal children was better predicted by their age than by the speech patterns of their mothers. Deaf children learned a gestural language in the same developmental increments that hearing children learned spoken language. Language onset and structural development were the same for blind as for sighted children. Finally, although the onset of language was late for Down syndrome children, its rate and nature of development paralleled that of normal children until a point when learning simply stopped. These results consistently point to the child's neurological age as a critical factor in his or her language learning.

Neurological age may also set limits on language learning in a manner different from what has already been discussed. Anecdotal evidence supports the hypothesis that children are better language learners than are adults. They easily manage two languages at a time while adults struggle through second language classes with great difficulty (Gleitman, 1986; cf. Miller, 1981). In addition, findings from studies investigating deaf individuals learning American sign language indicate that final knowledge of the language is best predicted by the age of the learner at first exposure (Newport & Supalla, cited in Gleitman, 1986). Late learners, in other words, failed to acquire all the linguistic structures of American sign language, despite years of subsequent exposure and use. This suggests the possibility of a critical period in language learning, akin to chick imprinting or bird song-learning.

Reflect back, for a moment, on the case of Mario, described at the beginning of this chapter. Although the scenario did not state which part of his brain sustained damage, we might assume that the left cerebral hemisphere was involved because his speech was affected. That Mario regained his speech may be taken as evidence for critical periods in language development. Lenneberg (1967) reported normal language development following damage to the left hemisphere at an early age but loss of linguistic ability when damage occurred after puberty. Recent studies may call Lenneberg's results into question, because more sophisticated psycholinguistic testing has revealed specific competence failures in the language of brain-damaged individuals. "Nevertheless, the clinical impression is that such persons are linguistically normal. The classical conclusion that the young brain is quite flexible in reallocating functions seems to remain valid" (Chipman, 1986, p. 212).

Finally, just as individuals exhibit differences in their preference for processing in certain modes, they also exhibit differences in the areas of the brain that subserve language functions. Females appear different from males, and left-handed persons appear different from right-handed persons. These differences do not, however, result in language deficiencies, which means there is much more to the story of language learning than we currently know.

Cognitive Development and the Brain

In at least one respect, studying cognitive development from a neurophysiological perspective is no different from studying it from a cognitive perspective. The primary question of interest is: To what extent is cognitive development biologically or environmentally determined? Obviously, behaviorists put little stock in biological factors, arguing that development can be fully understood in environmental terms. But cognitive developmentalists have been more open to the possibility of biological determinants in cognitive development. Piaget appealed to a biological model for understanding development, although his ideas never extended to investigations of actual biological processes or substrates of development. And Case suggested that maturation of certain brain systems may be responsible for limitations to children's working memory compared to adults (see Chapter 6).

To characterize the diversity of neuroscience research related to development, four conceptual models are suggested: fixed circuitry, critical periods, plasticity, and modularity (Chall & Peterson, 1986). To some degree, these models integrate much of the research already discussed concerning the neurophysiology of learning. They provide a useful working framework for a look at cognitive development and the brain.

Fixed Circuitry and Critical Periods. In normal prenatal development, what eventually becomes the brain begins as a single layer of cells lining the wall of the neural tube. Cell mitosis results in the genesis of waves of neurons which migrate to destinations in various parts of the developing brain. Elaboration of neuronal dendrites and synapses follows, with the establishment of connections between neurons the ultimate achievement of development (Goldman-Rakic, 1986). What is noteworthy about this process (highly oversimplified here) is the very orchestrated plan it requires. Brain cell generation and migration is virtually complete in humans by the sixteenth week after gestation. Neurons by then have assumed specific functions in specific regions of the brain. Although dendritic development and synapse formation take longer, generally continuing well into the postnatal period, they form particular patterns of connections that depend upon their location.

What do these fixed circuits and their pattern of development mean for learning and complex cognitive functioning? For one thing, the developing brain will be more or less sensitive to different types of injuries at different times. Dividing cells are now known to be selectively vulnerable to radiation; during the period of cell division, then, subsequent development of the brain can be irreparably harmed if it is exposed to radiation. This helps to explain why many women who survived Hiroshima, and who were 8 to 16 weeks pregnant at the time the atom bomb was dropped, gave birth to mentally retarded children. For children whose gestational age was outside this critical period, however, mental retardation was not common. As Goldman-Rakic (1986) put it, "Toxins, injuries, and stress-induced maternal influences can certainly alter the number of cells generated, their patterns of migration and ultimate synaptic connections" (p. 253). What effects there will be depends upon the critical periods during which the influences are felt.

Critical periods apparently occur not only before birth, but after as well. There is now evidence to believe that the brain may not be fully mature until individuals reach at least 8 to 10 years of age (Heminway & Tegriti, 1984), and a few researchers believe that figure is closer to 18 to 20 (Epstein, 1990). Moreover, data from electroencephalograms show evidence of growth spurts in the brain that some have attempted to correlate with Piaget's stages of cognitive development. This would suggest critical periods for learning that occur around the ages at which children make transitions among stages.

At this point, however, the correlations between brain maturation and Piaget's stages of development are at best weak. For one thing, very global measures of cognitive performance have been used, which are likely to have been insensitive to small increments in brain growth. For another, it has been difficult to reconcile the continuous rate of regional brain maturation with the discrete stage changes that Piaget's theory proposes (Hudspeth & Pribham, 1990). As a consequence, although it may be tempting to draw curricular implications from these data, McCall (1990) has argued that they would be premature.

Eventually, the more that is known about how and when circuits are fixed in the brain, the more likely we will be able to determine neurological causes of certain learning problems. Chall and Peterson (1986) expressed the hope, for example, that reading disabilities may be more accurately detected and treated with knowledge of their neurological origins and potential critical periods. Bruer (1999) also argued the need for developing and testing interventions to help learners who, for whatever reason, may have missed critical experiences during development. Thus, even though a critical period may have been passed, there is evidence that children can make up some of the lost ground.

Plasticity. On the other side of the coin from fixed circuitry is the cortical plasticity of the developing brain. It has already been mentioned that dendritic branching and synaptic formation continue after birth. In fact, although subject to critical periods, "anatomical plasticity during development of the nervous system...is the rule rather than the exception" (Crutcher, 1991, pp. 107–108). Yet, there is now ample evidence to suggest that cortical plasticity is characteristic of the brain throughout life. Rosenzweig (1984, 1986, 1998) described studies he and others conducted with rodents, investigating brain changes induced by experience. He compared the brain development of rats, mice, ground squirrels, and gerbils raised in standard, enriched, or impoverished environments. The standard environment consisted of a small laboratory cage for three rodents, furnished with food and water. The enriched environment was a larger cage for ten to twelve animals, with food, water, and a variety of objects changed daily (such as shelves and slides). The impoverished environment meant that each animal was raised alone in a small private cage.

Rosenzweig's results were rather astounding. The brains of animals raised in the enriched environment showed increases in weight, dendritic branching, and the size of synaptic contacts relative to the comparison groups. Moreover, the brains of adult rats showed a continued ability to change in response to experience, with these changes related to improvements in learning.

Studying neurological changes in the brain in response to experience is obviously more difficult when it concerns humans rather than rodents. Nonetheless, there is compelling evidence to believe that human brains are also characterized by plasticity. Studies analogous to those of Rosenzweig have been conducted in which researchers compared the cognitive abilities (as measured by IQ tests) of children raised in different types of environments (Friedman & Cocking, 1986). In general, results suggested the same conclusion. An enriched environment can significantly enhance cognitive development, especially when the enrichment comes at an early age.

Additional evidence of neuronal plasticity, this time in mature brains, is provided by studies of stroke victims who regained functions incapacitated by the stroke (Bach-y-Rita, 1980, 1982) and split-brain patients who regained the ability to produce speech years after a callosotomy (Gazzaniga et al., 1996). Despite these findings, however, there is also evidence that neuronal plasticity declines with age in many species, including humans (Crutcher, 1991; see also Barnes, 1998). This is thought to be a function of mature individuals committing increasing portions of their nervous system to memory storage. And memory storage, of necessity, must be relatively stable in order for information to be later recalled. It seems likely, then, that older learners are capable of learning new things throughout their lives, but doing so in a flexible manner is somewhat more difficult than it is for younger learners.

Modularity. Conceptualizing memory in terms of modules offers a means for understanding the differences between memories that are lost or retained with brain damage (Chall & Peterson, 1986). This is similar to the declarative-procedural distinction that has already been discussed. Modularity can also refer to differences of another sort. Gardner (1983, 1986) proposed that cognitive development proceeds independently in at least seven relatively autonomous domains, or modules—language, music, logical-mathematical reasoning, spatial processing, bodily-kinesthetic activity, interpersonal knowledge, and intrapersonal knowledge. These make up the sum of one's intelligence.

Evidence for brain modularity comes first from investigations of fixed circuits referred to earlier. Cortical connections associated with visual perception have been found to be arrayed in cellular columns (Hubel & Wiesel, 1962), but so have connections in the frontal cortex that are unrelated to sensory perception. "Modular organization seems to be a universal rule for disposition of connections in the cerebral cortex" (Goldman-Rakic, 1986, p. 249).

As for the different types of intelligences proposed by Gardner, language seems to be predominantly associated with the left cerebral hemisphere, visual-spatial abilities with the right hemisphere, music perception and production with the right anterior lobe, and emotional difficulties with the right temporal lobe (Gardner, 1986). These conclusions have been drawn from observations of mostly brain-damaged patients, but Gardner (1982, 1983) has also examined individuals from what he calls "unusual populations." These included idiot-savants, prodigies in single domains, and retarded individuals who may have a single spared organ of development. From his analyses, Gardner believes that normal individuals possess independent capacities to develop in the seven separate domains mentioned previously. Each domain is subserved by separate neural mechanisms, which can therefore be differentially affected by biological and environmental factors.

Finally, cognitive development in any domain is activated, according to Gardner (1986), within a cultural context. He argued that humans evolved as cultural members just as they evolved as biological creatures. Thus, biological potential is constrained to some extent by cultural factors within the environment. This argument is certainly consistent with the views of evolutionary psychologists and helps to provide a link between the neurophysiology of learning and the sociobiology of learning.

Implications of Neurophysiology for Learning and Instruction

There is likely to be unanimous agreement by this point that the neurophysiology of learning is a complex affair. Is it even possible to integrate the various perspectives described in order to draw sensible and useful implications for instruction? There appear to be at least five areas in which implications emerge, related to (1) modularity, (2) enriched environments, (3) plasticity, (4) language learning, and (5) learning problems. These are explained in the following discussion and summarized in Table 8.3.

Modularity and "Brain-Based" Curricula. Whether humans possess seven distinguishable cognitive capacities, as Gardner proposes, they undoubtedly possess some differentiation of cognitive function that is neurologically based. Both cognitive (see Chapter 3) and neurological findings point to differences between general (or procedural) and specific data-based (or declarative) memory. The same is true for different sensory codes that may be activated by attention to establish and access a single semantic memory. These findings, coupled with brain modularity and hemisphere differences that have been observed, suggest two implications.

First, learners are likely to demonstrate considerable variation in their processing preferences and cognitive abilities. If we agree that cognitive competence depends partly upon biological capacity and partly upon experience, then normal variation in both factors should produce extensive observed variability. This certainly comes as no surprise, but Gardner (1986) reminded us that education has routinely placed more emphasis on some types of cognition over others. This means that some learners may be disadvantaged compared to others if their cognitive strengths fall into areas generally overlooked by educators. The challenge to educators, then, is to discover each learner's cognitive profile, so that "we can make more informed decisions about which program of education to follow if we want to play from strength or if we want to shore up weaknesses" (Gardner, 1986, p. 278).

Gardner's statement leads directly to a second implication of modularity for curriculum and instruction. That is, how can educators use this knowledge of differences in memory and processing modes to provide learners with instruction most appropriate to their needs? For one thing, the

TABLE 8.3 ***Implications of Neurophysiology for Learning and Instruction***

Principle	*Implication for Instruction*
1. Cognitive functions are differentiated.	Learners are likely to have preferred modes of processing as well as different capabilities in various modes. This suggests a multimodal approach to instruction: Include activities that draw upon different sensory modes.
	For example, Ms. Lilly teaches geography locations using maps and songs. Students learn the locations of countries by singing the names as they locate and touch the countries on the map (November, 1992).
2. The brain is relatively plastic in nature.	Enriched, active environments are likely to facilitate learning in developing children. As for adults, although plasticity seems to decrease with age, learning can remain flexible if a variety of instructional strategies are offered.
	For example, children's literature can serve as an effective means to teach reading, and historic literature may be used effectively in social studies instruction.
3. Language may be biologically preprogrammed.	Children have implicit knowledge about language, which should be made explicit during language instruction. In addition, instructors should be aware that language problems could interfere with subject matter learning.
	For example, arithmetic problems should be phrased in language understood by the students.
4. Learning disorders may have a neurobiological basis.	Neurological testing may assist in diagnosing, treating, and evaluating the effectiveness of programs designed to ameliorate various learning problems.

existence of different memory types and cognitive capabilities implies different instructional strategies suitable for each type. In other words, acquiring a procedural skill in music is likely to demand different learning experiences than acquiring facts about logic. Once we better understand the nature of various cognitive capabilities, we will be in a better position to devise tasks appropriate to help learners progress in a particular domain.

This argument is similar to that which underlies Gagné's (1985) theory of instruction (see Chapter 10), as well as many models of instructional design (cf. Reigeluth, 1983). The difference among views appears to concern not whether learners acquire different capabilities but just what these capabilities are. It is hoped that future neurological research may help to sort out the possibilities.

Although domain differences suggest specific instructional strategies, learner differences may do so as well. There may be a problem, however, in the premature application of neuroscience findings to instruction. Educational programs that are designed to exercise both sides of the brain have been popular (Chipman, 1986; Rosenzweig, 1986). Other programs have used appeals to brain research to justify their emphasis on educating the right side of the brain or meeting the needs of predominantly "right-brained" learners. Such programs, however, "are certainly premature and probably misguided" (Rosenzweig, 1986, p. 352). Brain researchers stress the cooperative interaction between the two cerebral hemispheres and argue that their functional roles are only just beginning to be characterized. It would be simplistic to describe hemispheric differences as "analytic-holistic, verbal-spatial, or any others of the popular polar pairs that are often used for this purpose" (Bertelson, 1982, quoted in Rosenzweig, 1986, p. 352).

Although brain-based curricula are not well justified, instructional strategies that appeal to multiple sensory modes and cognitive capabilities probably are. Learners having difficulty understanding an instructional presentation in one mode may benefit from the same presentation in an alternate mode. Exploring how meaning can be conveyed differently in different modes can also be valuable for learning (cf. Tessmer, Wilson, & Driscoll, 1990) and constitutes a central tenet of semiotic (see Chapter 5) and constructivist (see Chapter 11) approaches to instruction. Not only may different pathways be established to the same memory, but that memory may be enhanced and broadened by unique contributions of different codes.

Use It or Lose It: Enriched Environments, Critical Periods, and Plasticity. During the postnatal period of the developing animal, synapses proliferate. Many more are produced by the young brain than are commonly seen in mature or adult brains. This initial overproduction of synapses is then followed by a period of consolidation, in which some synapses will be retracted until adult levels are reached (Goldman-Rakic, 1986). Although behavioral indicators of this sprouting and pruning period are still being determined, many researchers believe that it correlates with critical periods in cognitive development. This may help to explain, for example, why "certain precocious behaviors (like neonatal swimming or imitation) drop out" and why flexibility declines after a certain period (Gardner, 1986, p. 270).

Critical periods for the development of visual perception (cf. Hubel & Wiesel, 1962) are well established, and they are presumed to account for some observed differences in language learning, discussed earlier. There may also be critical periods in each of the seven domains of competence that Gardner has proposed. Whether or not Gardner's proposal is confirmed, what do critical periods in general suggest for instruction? At the least, they imply an important role for environmental events during the period of development deemed critical. Just what this role should be is the question.

In Piaget's view (see Chapter 6), equilibration is the major developmental process, implying that whereas environment provides the necessary raw material, the main impetus for development comes from within the learner. Consistent with this view was Piaget's opposition to speeding up development through instructional interventions. Most educators in the Piagetian tradition, then, would consider enriched environments to be those that provide a variety of resources promoting child activity.

By contrast, Bruner and Vygotsky (see Chapter 7) accorded the environment a more extensive role, believing that instruction can precede and contribute to development. Similarly, biological evidence from studies of enriched versus impoverished environments supports the influence of environment on development (Friedman & Cocking, 1986). Enrichment can take the form of guided learning or formal, planned instruction. Guided learning includes such tactics as parents, siblings, or peers helping children solve problems, prepare for school tests, or read challenging books. In fact, more challenging textbooks have been associated with higher Scholastic Aptitude Test (SAT) scores, and more difficult books appear to promote language and reading achievement (Chall & Peterson, 1986).

Because critical periods typically occur early in development, with both brain and behavior exhibiting less flexibility over time, a common assumption has been that cortical plasticity may be restricted to early development. However, Rosenzweig's findings effectively debunked this notion. "While acknowledging the importance of the developmental processes that set the stage before birth for later cognitive development and accomplishments, it seems to me that it is equally if not more vital for educators and cognitive scientists to know about the capacity of the nervous system, even in adults, to undergo plastic changes in response to experience" (Rosenzweig, 1986, p. 365).

In clear agreement with Rosenzweig are Friedman and Cocking (1986), who extended their notion of guided learning to include experts helping novices complete a task or generate important questions and therapists helping patients recover functions lost through accident or illness. Their point is that instruction of all sorts can facilitate changes in brain processes. What needs to be better understood, however, are the separate roles of learner motivation and maturity, family support, experience, and patience (Friedman & Cocking, 1986).

Language Learning. What help to educators is offered by knowledge that language may be biologically preprogrammed? Perhaps it comes down to one simple maxim:

> ...much of what is taught—and should be taught—about language to children is already known to the children implicitly.... I believe that the best teaching methods will be those that specifically take advantage of this prior knowledge, that call the child's attention to what she or he knows, and build as directly as possible from that knowledge. (Gleitman, 1986, pp. 144–145)

This maxim, it seems to me, suggests two related implications for instruction.

First, teachers of multicultural classrooms would be well advised to consider nonstandard English as a language or languages other than English. In other words, children from predominantly black or other ethnic neighborhoods typically speak English in a way that sounds wrong to most teachers. It is certainly wrong in the sense that it does not conform to the rules of standard English. But neither do other, so-called foreign languages; they have their own internal structure and grammatical rules. The same appears to be true for black English and other forms of nonstandard English. Thus, children of all backgrounds probably speak quite grammatically in the language of their surroundings. Knowing this may help teachers to determine what implicit knowledge children have of their language and to use this to best advantage in teaching standard English.

Second, differential patterns of language development are likely to be reflected in the differential difficulty of various language tasks. For example, "children are able to think about and manipulate word- and syllable-level representations of language much earlier in life than they can do the same for phoneme-segment representations of language" (Gleitman, 1986, p. 145). Thus, to be most effective, language instruction should proceed in the same sequence, helping to draw out and call attention to students' implicit knowledge about language.

This relation between language knowledge and task difficulty is also important to remember in other areas of instruction besides language itself. Recent studies in arithmetic problem solving have shown that the linguistic structure of a word problem can greatly influence its difficulty. For example, consider the two simple problems below.

> *Problem A:* John has 5 apples. Mary has 8 apples. How many more apples does Mary have than John?
>
> *Problem B:* John has 5 apples. Mary has 8 apples. If Mary gives Sally the same number of apples as John, how many will she have left?

Ostensibly, these two problems are the same, in that they are both solved by subtracting 5 from 8. If subtraction is the skill to be assessed, then either problem presumably should suffice. However, the problems are not linguistically the same, and, in fact, one is more difficult to answer than the other. You are right if you guessed Problem A to be the more difficult one. Concepts of more than and less than appear later in language use than concepts of adding to or taking away. Thus, word problems of this sort can assess linguistic competence and, indeed, mask arithmetic competence. Recall, as well, the influence of schemata on arithmetic problem solving that was discussed in Chapter 4 and the conception of language as a sign system that was discussed in Chapter 7. It seems likely that different linguistic structures will trigger different problem schemata or sign understandings, which may either enhance or interfere with solving the problem at hand.

Learning Disabilities and Their Treatment. There is great hope that neurological testing will some day be sophisticated enough to detect and diagnose a variety of learning problems. However, better diagnosis does not make the problem go away. Rather, the challenge lies in designing effective educational programs to overcome the learning difficulty. The solutions to that challenge are as apt to come from elsewhere as from advances in the neurophysiology of learning (Chipman, 1986).

Perhaps two additional points are salient here. The first concerns how we characterize what neurological causes are discovered for various learning problems. Calling such causes "defects in cerebral architecture" may signify to some people that they are immutable, impossible to alter or fix. Such an assumption might lead to the unwarranted abandonment of efforts to remediate the learning problem. On the other hand, finding neurological bases of cognitive functions does not have to imply that some functioning is normal and some defective. Rather, one might expect the brains of two individuals to be different, with one possessing some skill that the other lacks. Neural indicators of this sort might be helpful as an additional source of information used to evaluate the effectiveness of educational programs (Chipman, 1986).

Finally, it pays us to remember the neurological evidence of brain plasticity. Chall and Peterson (1986) suggested that we adopt the view of the learner as "an active constructor of knowledge, and the brain as a structure that changes physically as well as behaviorally with learning" (p. 314). Learners do overcome disabilities, albeit sometimes with great difficulty and prolonged effort.

A Biological Understanding of "Kermit and the Keyboard"

A reasonable assumption to make about Kermit in this story is that he is a normal adult male who has not yet faced the potential ravages of old age such as strokes or Alzheimer's disease. We know that he studied music formally "many years ago," but we do not know whether this occurred while he was a small child or whether music lessons began for him as it does for many children—at the age of 7 or 8 (or later). Therefore, it is impossible to speculate on the role critical periods may have played in his early music learning or whether his parents sought to enrich his environment with experiences that might have enhanced this learning. Likewise, there is no evidence to suggest that Kermit suffers from any sort of attentional problem. Quite the opposite—he demonstrates that he can focus his attention appropriately in coordinating his reading the music and playing the corresponding notes.

The biological concepts that are perhaps most clearly illustrated in this story are those pertaining to different memory systems. Using Schacter and Tulving's classification system, we can see that several memory systems appear to be involved in Kermit's learning. The motor skill of playing the keyboard invokes the procedural system, whereas reading the music invokes the primary, semantic, and perceptual systems. The conditioning of the mistake that becomes part of Kermit's repertoire also appears to involve the procedural system. Similarly, this could be understood as a kind of priming, which in Squire's taxonomy (Figure 8.5) would be an example of nondeclarative, or implicit, memory. That is, because of the association Kermit has made between playing that note a particular way and the background that accompanies his playing, the background serves to prime, or cue, Kermit to play the note wrong. The implicit nature of the memory means that he is unlikely to become aware of the mistake until someone points it out, or makes it explicit.

According to neuropsychology, all of the experiences that Kermit has with his keyboard cause modifications in his brain that organize and encode his learning. As long as he continues to practice and experience new things, these modifications will continue to occur and reorganize with his growing proficiency.

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Theory Matrix

Theory	Biological Bases of Learning
Prominent Theorists	L. Cosmides (evolution); M. S. Gazzaniga; M. R. Rosenzweig; D. L. Schacter (neuropsychology)
Learning Outcome(s)	Thoughts, behaviors, emotions, physical changes in the brain
Role of the Learner	Interact with a hierarchy of environments
Role of the Instructor	Understand the interactive relation between nature and nurture Attempt to determine what things in learning are tied to critical periods for development Provide rich, complex, and engaging learning environments and allow for practice
Inputs or Preconditions to Learning	Maturation, different kinds of experiences
Process of Learning	Synaptic formation and pruning; organizing and reorganizing brain structures

Suggested Readings

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Reflective Questions and Activities

1. What underlying assumptions about knowledge and knowing can be detected in the research presented in this chapter? Are they different among researchers interested in ultimate causes versus those interested in proximal causes of learning? With what epistemological tradition do these views seem most closely related?