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Mind and Brain

As the popular press has discovered, people have a keen appetite for research information about how the brain works and how thought processes develop (*Newsweek*, 1996, 1997; *Time*, 1997a, b). Interest runs particularly high in stories about the neuro-development of babies and children and the effect of early experiences on learning. The fields of neuroscience and cognitive science are helping to satisfy this fundamental curiosity about how people think and learn.

In considering which findings from brain research are relevant to human learning or, by extension, to education, one must be careful to avoid adopting faddish concepts that have not been demonstrated to be of value in classroom practice. Among these is the concept that the left and right hemispheres of the brain should be taught separately to maximize the effectiveness of learning. Another is the notion that the brain grows in holistic "spurts," within or around which specific educational objectives should be arranged: as discussed in this chapter, there is significant evidence that brain regions develop asynchronously, although any specific educational implications of this remain to be determined. Another widely held misconception is that people use only 20 percent of their brains—with different percentage figures in different incarnations—and should be able to use more of it. This belief appears to have arisen from the early neuroscience finding that much of the cerebral cortex consists of "silent areas" that are not activated by sensory or motor activity. However, it is now known that these silent areas mediate higher cognitive functions that are not directly coupled to sensory or motor activity.

Advances in neuroscience are confirming theoretical positions advanced by developmental psychology for a number of years, such as the importance of early experience in development (Hunt, 1961). What is new, and therefore important for this volume, is the *convergence* of evidence from a number of scientific fields. As the sciences of developmental psychology, cognitive psychology, and neuroscience, to name but three, have contributed vast numbers of research studies, details about learning and development have converged to form a more complete picture of how intellectual development occurs. Clarification of some of the mechanisms of learning by neuroscience has been advanced, in part, by the advent of non-invasive imaging technologies, such as positron emission tomography (PET) and functional magnetic resonance imaging (FMRI). These technologies have allowed researchers to observe human learning processes directly.

This chapter reviews key findings from neuroscience and cognitive science that are expanding knowledge of the mechanisms of human learning. Three main points guide the discussion in this chapter:

1. Learning changes the physical structure of the brain.
2. These structural changes alter the functional organization of the brain; in other words, learning organizes and reorganizes the brain.
3. Different parts of the brain may be ready to learn at different times.

We first explain some basic concepts of neuroscience and new knowledge about brain development, including the effects of instruction and learning on the brain. We then look at language in learning as an example of the mind-brain connection. Lastly, we examine research on how memory is represented in the brain and its implications for learning.

From a neuroscience perspective, instruction and learning are very important parts of a child's brain development and psychological development processes. Brain development and psychological development involve continuous interactions between a child and the external environment—or, more accurately, a hierarchy of environments, extending from the level of the individual body cells to the most obvious boundary of the skin. Greater understanding of the nature of this interactive process renders moot such questions as how much depends on genes and how much on environment. As various developmental researchers have suggested, this question is much like asking which contributes most to the area of a rectangle, its height or its width (Eisenberg, 1995)?

THE BRAIN: FOUNDATION FOR LEARNING

Neuroscientists study the anatomy, physiology, chemistry, and molecular biology of the nervous system, with particular interest in how brain activity relates to behavior and learning. Several crucial questions about early learning particularly intrigue neuroscientists. How does the brain develop? Are there stages of brain development? Are there critical periods when certain things must happen for the brain to develop normally? How is information encoded in the developing and the adult nervous systems? And perhaps most important: How does experience affect the brain?

Some Basics

A nerve cell, or neuron, is a cell that receives information from other nerve cells or from the sensory organs and then projects that information to other nerve cells, while still other neurons project it back to the parts of the body that interact with the environment, such as the muscles. Nerve cells are equipped with a cell body—a sort of metabolic heart—and an enormous treelike structure called the dendritic field, which is the input side of the neuron. Information comes into the cell from projections called axons. Most of the excitatory information comes into the cell from the dendritic field, often through tiny dendritic projections called spines. The junctions through which information passes from one neuron to another are called synapses, which can be excitatory or inhibitory in nature. The neuron integrates the information it receives from all of its synapses and this determines its output.

During the development process, the "wiring diagram" of the brain is created through the formation of synapses. At birth, the human brain has in place only a relatively small proportion of the trillions of synapses it will eventually have; it gains about two-thirds of its adult size after birth. The rest of the synapses are formed after birth, and a portion of this process is guided by experience.

Synaptic connections are added to the brain in two basic ways. The first way is that synapses are overproduced, then selectively lost. Synapse overproduction and loss is a fundamental mechanism that the brain uses to incorporate information from experience. It tends to occur during the early periods of development. In the visual cortex—the area of the cerebral cortex of the brain that controls sight—a person has many more synapses at 6 months of age than at adulthood. This is because more and more synapses are formed in the early months of life, then they disappear, sometimes in prodigious numbers. The time required for this phenomenon to run its course varies in different parts of the brain, from 2 to 3 years in the human visual cortex to 8 to 10 years in some parts of the frontal cortex.

Some neuroscientists explain synapse formation by analogy to the art of sculpture. Classical artists working in marble created a sculpture by chiseling away unnecessary bits of stone until they achieved their final form. Animal studies suggest that the "pruning" that occurs during synapse overproduction and loss is similar to this act of carving a sculpture. The nervous system sets up a large number of connections; experience then plays on this network, selecting the appropriate connections and removing the inappropriate ones. What remains is a refined final form that constitutes the sensory and perhaps the cognitive bases for the later phases of development.

The second method of synapse formation is through the addition of new synapses—like the artist who creates a sculpture by adding things together until the form is complete. Unlike synapse overproduction and loss, the process of synapse addition operates throughout the entire human life span and is especially important in later life. This process is not only sensitive to experience, it is actually driven by experience. Synapse addition probably lies at the base of some, or even most, forms of memory. As discussed later in this chapter, the work of cognitive scientists and education researchers is contributing to our understanding of synapse addition.

Wiring the Brain

The role of experience in wiring the brain has been illuminated by research on the visual cortex in animals and humans. In adults, the inputs entering the brain from the two eyes terminate separately in adjacent regions of the visual cortex. Subsequently, the two inputs converge on the next set of neurons. People are not born with this neural pattern. But through the normal processes of seeing, the brain sorts things out.

Neuroscientists discovered this phenomenon by studying humans with visual abnormalities, such as a cataract or a muscle irregularity that deviates the eye. If the eye is deprived of the appropriate visual experience at an early stage of development (because of such abnormalities), it loses its ability to transmit visual information into the central nervous system. When the eye that was incapable of seeing at a very early age was corrected later, the correction alone did not help—the afflicted eye still could not see. When researchers looked at the brains of monkeys in which similar kinds of experimental manipulations had been made, they found that the normal eye had captured a larger than average amount of neurons, and the impeded eye had correspondingly lost those connections.

This phenomenon only occurs if an eye is prevented from experiencing normal vision very early in development. The period at which the eye is sensitive corresponds to the time of synapse overproduction and loss in the visual cortex. Out of the initial mix of overlapping inputs, the neural connections that belong to the eye that sees normally tend to survive, while the connections that belong to the abnormal eye wither away. When both eyes see normally, each eye loses some of the overlapping connections, but both keep a normal number.

In the case of deprivation from birth, one eye completely takes over. The later the deprivation occurs after birth, the less effect it has. By about 6 months of age, closing one eye for weeks on end will produce no effect whatsoever. The critical period has passed; the connections have already sorted themselves out, and the overlapping connections have been eliminated.

This anomaly has helped scientists gain insights into normal visual development. In normal development, the pathway for each eye is sculpted (or "pruned") down to the right number of connections, and those connections are sculpted in other ways, for example, to allow one to see patterns. By overproducing synapses then selecting the right connections, the brain develops an organized wiring diagram that functions optimally. The brain development process actually uses visual information entering from outside to become more precisely organized than it could with intrinsic molecular mechanisms alone. This external information is even more important for later cognitive development. The more a person interacts with the world, the more a person needs information from the world incorporated into the brain structures.

Synapse overproduction and selection may progress at different rates in different parts of the brain (Huttenlocher and Dabholkar, 1997). In the primary visual cortex, a peak in synapse density occurs relatively quickly. In the medial frontal cortex, a region clearly associated with higher cognitive functions, the process is more protracted: synapse production starts before birth and synapse density continues to increase until 5 or 6 years of age. The selection process, which corresponds conceptually to the main organization of patterns, continues during the next 4-5 years and ends around early adolescence. This lack of synchrony among cortical regions may also occur upon individual cortical neurons where different inputs may mature at different rates (see Juraska, 1982, on animal studies).

After the cycle of synapse overproduction and selection has run its course, additional changes occur in the brain. They appear to include both the modification of existing synapses and the addition of entirely new synapses to the brain. Research evidence (described in the next section) suggests that activity in the nervous system associated with learning experiences somehow causes nerve cells to create new synapses. Unlike the process of synapse overproduction and loss, synapse addition and modification are lifelong processes, driven by experience. In essence, the quality of information to which one is exposed and the amount of information one acquires is reflected throughout one's life in the structure of the brain. This process is probably not the only way that information is stored in the brain, but it is a very important way that provides insight into how people learn.

EXPERIENCES AND ENVIRONMENTS FOR BRAIN DEVELOPMENT

Alterations in the brain that occur during learning seem to make the nerve cells more efficient or powerful. Animals raised in complex environments have a greater volume of capillaries per nerve cell—and therefore a greater supply of blood to the brain—than the caged animals, regardless of whether the caged animal lived alone or with companions (Black et al., 1987). (Capillaries are the tiny blood vessels that supply oxygen and other nutrients to the brain.) In this way experience increases the overall quality of functioning of the brain. Using astrocytes (cells that support neuron functioning by providing nutrients and removing waste) as the index, there are higher amounts of astrocyte per neuron in the complex-environment animals than in the caged groups. Overall, these studies depict an orchestrated pattern of increased capacity in the brain that depends on experience.

Other studies of animals show other changes in the brain through learning; see Box 5.1. The weight and thickness of the cerebral cortex can be measurably altered in rats that are reared from weaning, or placed as adults, in a large cage enriched by the presence both of a changing set of objects for play and exploration and of other rats to induce play and exploration (Rosenzweig and Bennett, 1978). These animals also perform better on a variety of problem-solving tasks than rats reared in standard laboratory cages. Interestingly, both the interactive presence of a social group and direct physical contact with the environment are important factors: animals placed in the enriched environment alone showed relatively little benefit; neither did animals placed in small cages within the larger environment (Ferchmin et al., 1978; Rosenzweig and Bennett, 1972). Thus, the gross structure of the cerebral cortex was altered both by exposure to opportunities for learning and by learning in a social context.

Does Mere Neural Activity Change the Brain or Is Learning Required?

Are the changes in the brain due to actual learning or to variations in aggregate levels of neural activity? Animals in a complex environment not only learn from experiences, but they also run, play, and exercise, which activates the brain. The question is whether activation alone can produce brain changes without the subjects actually learning anything, just as activation of muscles by exercise can cause them to grow. To answer this question, a group of animals that learned challenging motor skills but had relatively little brain activity was compared with groups that had high levels of brain activity but did relatively little learning (Black et al., 1990). There were four groups in all. One group of rats was taught to traverse an elevated obstacle course; these "acrobats" became very good at the task over a month or so of practice. A second group of "mandatory exercisers" was put on a treadmill once a day, where they ran for 30 minutes, rested for 10 minutes, then ran another 30 minutes. A third group of "voluntary exercisers" had free access to an activity wheel attached directly to their cage, which they used often. A control group of "cage potato" rats had no exercise.

What happened to the volume of blood vessels and number of synapses per neuron in the rats? Both the mandatory exercisers and the voluntary exercisers showed higher densities of blood vessels than either the cage potato rats or the acrobats, who learned skills that did not involve significant

BOX 5.1 Making Rats Smarter

How do rats learn? Can rats be "educated?" In classic studies, rats are placed in a complex communal environment filled with objects that provide ample opportunities for exploration and play (Greenough, 1976). The objects are changed and rearranged each day, and during the changing time, the animals are put in yet another environment with another set of objects. So, like their real-world counterparts in the sewers of New York or the fields of Kansas, these rats have a relatively rich set of experiences from which to draw information. A contrasting group of rats is placed in a more typical laboratory environment, living alone or with one or two others in a barren cage—which is obviously a poor model of a rat's real world. These two settings can help determine how experience affects the development of the normal brain and normal cognitive structures, and one can also see what happens when animals are deprived of critical experiences.

After living in the complex or impoverished environments for a period from weaning to rat adolescence, the two groups of animals were subjected to a learning experience. The rats that had grown up in the complex environment made fewer errors at the outset than the other rats; they also learned more quickly not to make any errors at all. In this sense, they were smarter than their more deprived counterparts. And with positive rewards, they performed better on complex tasks than the animals raised in individual cages. Most significant, learning altered the rats' brains: the animals from the complex environment had 20-25 percent more synapses per nerve cell in the visual cortex than the animals from the standard cages (see Turner and Greenough, 1985; Beaulieu and Colonnier, 1987). It is clear that when animals learn, they add new connections to the wiring of their brains—a phenomenon not limited to early development (see, e.g., Greenough et al., 1979).

amounts of activity. But when the number of synapses per nerve cell was measured, the acrobats were the standout group. Learning adds synapses; exercise does not. Thus, different kinds of experience condition the brain in different ways. Synapse formation and blood vessel formation (vascularization) are two important forms of brain adaptation, but they are driven by different physiological mechanisms and by different behavioral events.

Localized Changes

Learning specific tasks brings about localized changes in the areas of the brain appropriate to the task. For example, when young adult animals were taught a maze, structural changes occurred in the visual area of the cerebral cortex (Greenough et al., 1979). When they learned the maze with one eye blocked with an opaque contact lens, only the brain regions connected to the open eye were altered (Chang and Greenough, 1982). When they learned a set of complex motor skills, structural changes occurred in the motor region of the cerebral cortex and in the cerebellum, a hindbrain structure that coordinates motor activity (Black et al., 1990; Kleim et al., 1996).

These changes in brain structure underlie changes in the functional organization of the brain. That is, learning imposes new patterns of organization on the brain, and this phenomenon has been confirmed by electrophysiological recordings of the activity of nerve cells (Beaulieu and Cynader, 1990). Studies of brain development provide a model of the learning process at a cellular level: the changes first observed in rats have also proved to be true in mice, cats, monkeys, and birds, and they almost certainly occur in humans.

ROLE OF INSTRUCTION IN BRAIN DEVELOPMENT

Clearly, the brain can store information, but what kinds of information? The neuroscientist does not address these questions. Answering them is the job of cognitive scientists, education researchers, and others who study the effects of experiences on human behavior and human potential. Several examples illustrate how instruction in specific kinds of information can influence natural development processes. This section discusses a case involving language development.

Language and Brain Development

Brain development is often timed to take advantage of particular experiences, such that information from the environment helps to organize the brain. The development of language in humans is an example of a natural process that is guided by a timetable with certain limiting conditions. Like the development of the visual system, parallel processes occur in human language development for the capacity to perceive phonemes, the "atoms" of speech. A phoneme is defined as the smallest meaningful unit of speech sound. Human beings discriminate the "b" sound from the "p" sound largely by perceiving the time of the onset of the voice relative to the time the lips part; there is a boundary that separates "b" from "p" that helps to distinguish "bet" from "pet." Boundaries of this sort exist among closely related phonemes, and in adults these boundaries reflect language experience. Very young children discriminate many more phonemic boundaries than adults, but they lose their discriminatory powers when certain boundaries are not supported by experience with spoken language (Kuhl, 1993). Native Japanese speakers, for example, typically do not discriminate the "r" from the "l" sounds that are evident to English speakers, and this ability is lost in early childhood because it is not in the speech that they hear. It is not known whether synapse overproduction and elimination underlies this process, but it certainly seems plausible.

The process of synapse elimination occurs relatively slowly in the cerebral cortical regions that are involved in aspects of language and other higher cognitive functions (Huttenlocher and Dabholkar, 1997). Different brain systems appear to develop according to different time frames, driven in part by experience and in part by intrinsic forces. This process suggests that children's brains may be more ready to learn different things at different times. But, as noted above, learning continues to affect the structure of the brain long after synapse overproduction and loss are completed. New synapses are added that would never have existed without learning, and the wiring diagram of the brain continues to be reorganized throughout one's life. There may be other changes in the brain involved in the encoding of learning, but most scientists agree that synapse addition and modification are the ones that are most certain.

Examples of Effects of Instruction on Brain Development

Detailed knowledge of the brain processes that underlie language has emerged in recent years. For example, there appear to be separate brain areas that specialize in subtasks such as hearing words (spoken language of others), seeing words (reading), speaking words (speech), and generating words (thinking with language). Whether these patterns of brain organization for oral, written, and listening skills require separate exercises to promote the component skills of language and literacy remains to be determined. If these closely related skills have somewhat independent brain representation, then coordinated practice of skills may be a better way to encourage learners to move seamlessly among speaking, writing, and listening.

Language provides a particularly striking example of how instructional processes may contribute to organizing brain functions. The example is interesting because language processes are usually more closely associated with the left side of the brain. As the following discussion points out, specific kinds of experiences can contribute to other areas of the brain taking over some of the language functions. For example, deaf people who learn a sign language are learning to communicate using the visual system in place of the auditory system. Manual sign languages have grammatical structures, with affixes and morphology, but they are not translations of spoken languages. Each particular sign language (such as American Sign Language) has a unique organization, influenced by the fact that it is perceived visually. The perception of sign language depends on parallel visual perception of shape, relative spatial location, and movement of the hands—a very different type of perception than the auditory perception of spoken language (Bellugi, 1980).

In the nervous system of a hearing person, auditory system pathways appear to be closely connected to the brain regions that process the features of spoken language, while visual pathways appear to go through several stages of processing before features of written language are extracted (Blakemore, 1977; Friedman and Cocking, 1986). When a deaf individual learns to communicate with manual signs, different nervous system processes have replaced the ones normally used for language—a significant achievement.

Neuroscientists have investigated how the visual-spatial and language processing areas each come together in a different hemisphere of the brain, while developing certain new functions as a result of the visual language experiences. In the brains of all deaf people, some cortical areas that normally process auditory information become organized to process visual information. Yet there are also demonstrable differences among the brains of deaf people who use sign language and deaf people who do not use sign language, presumably because they have had different language experiences (Neville, 1984, 1995). Among other things, major differences exist in the electrical activities of the brains of deaf individuals who use sign language and those who do not know sign language (Friedman and Cocking, 1986; Neville, 1984). Also, there are similarities between sign language users with normal hearing and sign language users who are deaf that result from their common experiences of engaging in language activities. In other words, specific types of instruction can modify the brain, enabling it to use alternative sensory input to accomplish adaptive functions, in this case, communication.

Another demonstration that the human brain can be functionally reorganized by instruction comes from research on individuals who have suffered strokes or had portions of the brain removed (Bach-y-Rita, 1980, 1981; Crill and Raichle, 1982). Since spontaneous recovery is generally unlikely, the best way to help these individuals regain their lost functions is to provide them with instruction and long periods of practice. Although this kind of learning typically takes a long time, it can lead to partial or total recovery of functions when based on sound principles of instruction. Studies of animals with similar impairments have clearly shown the formation of new brain connections and other adjustments, not unlike those that occur when adults learn (e.g., Jones and Schallert, 1994; Kolb, 1995). Thus, guided learning and learning from individual experiences both play important roles in the functional reorganization of the brain.

MEMORY AND BRAIN PROCESSES

Research into memory processes has progressed in recent years through the combined efforts of neuroscientists and cognitive scientists, aided by positron emission tomography and functional magnetic resonance imaging (Schacter, 1997). Most of the research advances in memory that help scientists understand learning come from two major groups of studies: studies that show that memory is not a unitary construct and studies that relate features of learning to later effectiveness in recall.

Memory is neither a single entity nor a phenomenon that occurs in a single area of the brain. There are two basic memory processes: declarative memory, or memory for facts and events which occurs primarily in brain systems involving the hippocampus; and procedural or nondeclarative memory, which is memory for skills and other cognitive operations, or memory that cannot be represented in declarative sentences, which occurs principally in the brain systems involving the neostriatum (Squire, 1997).

Different features of learning contribute to the durability or fragility of memory. For example, comparisons of people's memories for words with their memories for pictures of the same objects show a superiority effect for pictures. The superiority effect of pictures is also true if words and pictures are combined during learning (Roediger, 1997). Obviously, this finding has direct relevance for improving the long-term learning of certain kinds of information.

Research has also indicated that the mind is not just a passive recorder of events, rather, it is actively at work both in storing and in recalling information. There is research demonstrating that when a series of events are presented in a random sequence, people reorder them into sequences that make sense when they try to recall them (Lichtenstein and Brewer, 1980). The phenomenon of the active brain is dramatically illustrated further by the fact that the mind can "remember" things that actually did not happen. In one example (Roediger, 1997), people are first given lists of words: sour-candy-sugar-bitter-good-taste-tooth-knife-honey-photo-chocolate-heart-cake-tart-pie. During the later recognition phase, subjects are asked to respond "yes" or "no" to questions of whether a particular word was on the list. With high frequency and high reliability, subjects report that the word "sweet" was on the list. That is, they "remember" something that is not correct. The finding illustrates the active mind at work using inferencing processes to relate events. People "remember" words that are implied but not stated with the same probability as learned words. In an act of efficiency and "cognitive economy" (Gibson, 1969), the mind creates categories for processing information. Thus, it is a feature of learning that memory processes make relational links to other information.

In view of the fact that experience alters brain structures and that specific experiences have specific effects on the brain, the nature of "experience" becomes an interesting question in relation to memory processes. For example, when children are asked if a false event has ever occurred (as verified by their parents), they will correctly say that it never happened to them (Ceci, 1997). However, after repeated discussions around the same false events spread over time, the children begin to identify these false events as true occurrences. After about 12 weeks of such discussions, children give fully elaborated accounts of these fictitious events, involving parents, siblings, and a whole host of supporting "evidence." Repeating lists of words with adults similarly reveals that recalling non-experienced events activates the same regions of the brain as events or words that were directly experienced (Schacter, 1997). Magnetic resonance imaging also shows that the same brain areas are activated during questions and answers about both true and false events. This may explain why false memories can seem so compelling to the individual reporting the events.

In sum, classes of words, pictures, and other categories of information that involve complex cognitive processing on a repeated basis activate the brain. Activation sets into motion the events that are encoded as part of long-term memory. Memory processes treat both true and false memory events similarly and, as shown by imaging technologies, activate the same brain regions, regardless of the validity of what is being remembered. Experience is important for the development of brain structures, and what is registered in the brain as memories of experiences can include one's own mental activities.

These points about memory are important for understanding learning and can explain a good deal about why experiences are remembered well or poorly. Particularly important is the finding that the mind imposes structure on the information available from experience. This parallels descriptions of the organization of information in skilled performance discussed in Chapter 3: one of the primary differences between the novice and the expert is the manner in which information is organized and utilized. From the perspective of teaching, it again suggests the importance of an appropriate overall framework within which learning occurs most efficiently and effectively (see evidence discussed in Chapters 3 and 4).

Overall, neuroscience research confirms the important role that experience plays in building the structure of the mind by modifying the structures of the brain: development is not solely the unfolding of preprogrammed patterns. Moreover, there is a convergence of many kinds of research on some of the rules that govern learning. One of the simplest rules is that practice increases learning; in the brain, there is a similar relationship between the amount of experience in a complex environment and the amount of structural change.

In summary, neuroscience is beginning to provide some insights, if not final answers, to questions of great interest to educators. There is growing evidence that both the developing and the mature brain are structurally altered when learning occurs. Thus, these structural changes are believed to encode the learning in the brain. Studies have found alterations in the weight and thickness of the cerebral cortex of rats that had direct contact with a stimulating physical environment and an interactive social group. Subsequent work has revealed underlying changes in the structure of nerve cells and of the tissues that support their function. The nerve cells have a greater number of the synapses through which they communicate with each other. The structure of the nerve cells themselves is correspondingly altered. Under at least some conditions, both astrocytes that provide support to the neurons and the capillaries that supply blood may also be altered. The learning of specific tasks appears to alter the specific regions of the brain involved in the task. These findings suggest that the brain is a dynamic organ, shaped to a great extent by experience—by what a living being does, and has done.

CONCLUSION

It is often popularly argued that advances in the understanding of brain development and mechanisms of learning have substantial implications for education and the learning sciences. In addition, certain brain scientists have offered advice, often with a tenuous scientific basis, that has been incorporated into publications designed for educators (see, e.g., Sylwester, 1995:Ch. 7). Neuroscience has advanced to the point where it is time to think critically about the form in which research information is made available to educators so that it is interpreted appropriately for practice—identifying which research findings are ready for implementation and which are not.

This chapter reviews the evidence for the effects of experience on brain development, the adaptability of the brain for alternative pathways to learning, and the impact of experience on memory. Several findings about the brain and the mind are clear and lead to the next research topics:

1. The functional organization of the brain and the mind depends on and benefits positively from experience.

2. Development is not merely a biologically driven unfolding process, but also an active process that derives essential information from experience.

3. Research has shown that some experiences have the most powerful effects during specific sensitive periods, while others can affect the brain over a much longer time span.

4. An important issue that needs to be determined in relation to educa-

tion is which things are tied to critical periods (e.g., some aspects of phonemic perception and language learning) and for which things is the time of exposure less critical.

From these findings, it is clear that there are qualitative differences among kinds of learning opportunities. In addition, the brain "creates" informational experiences through mental activities such as inferencing, category formation, and so forth. These are types of learning opportunities that can be facilitated. By contrast, it is a bridge too far, to paraphrase John Bruer (1997), to suggest that specific activities lead to neural branching (Cardellichio and Field, 1997), as some interpreters of neuroscience have implied.