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CHAPTER 9

Cognition: Information Processing

THE INFORMATION-PROCESSING APPROACH

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CHAPTER RECAP
Summary of Developmental Themes
Summary of Topics

Key Themes in Cognition

- **Nature/Nurture** What roles do nature and nurture play in cognitive development?
- **Sociocultural Influence** How does the sociocultural context influence cognitive development?
- **Child's Active Role** How does the child play an active role in the process of cognitive development?
- **Continuity/Discontinuity** Is cognitive development continuous or discontinuous?
- **Individual Differences** How prominent are individual differences in cognitive development?
- **Interaction Among Domains** How does cognitive development interact with development in other domains?

"Tomorrow's geography test is going to be really tough," Nate lamented to his friend on the way home from school. "I should have paid more attention in class and kept up with my assignments. Now I have to study so much!" Normally a good student, Nate had been preoccupied with the success of his baseball team. Now there was a price to be paid as he prepared for the next day's test, and he was decidedly anxious about it. Nate had made up one "trick" for remembering the states in the Southeast: he strung their first letters to make the phrase "True aces forget no states" for Tennessee, Alabama, Florida, Georgia, North Carolina, and South Carolina, respectively. And it helped him to identify some of the states by tying their shapes to things he knew; for example, Florida really did look as though it had a "panhandle." But there was so much more to remember! Maybe he could just repeat the capitals of the states over and over to himself. One thing he knew for sure: next time he would not save all of his studying for the night before the test.

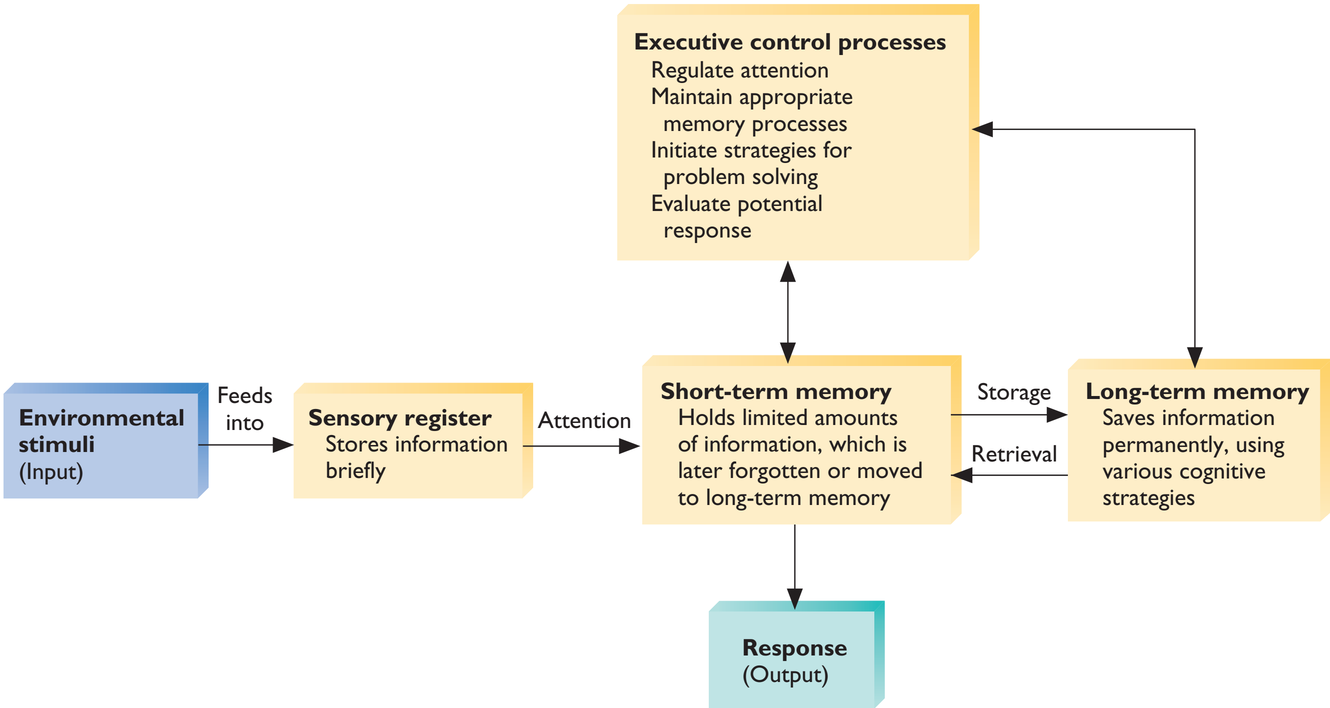
Nate, as it turns out, had a pretty good understanding of his mental capabilities. He knew that paying attention in class was helpful and that certain techniques, such as rehearsal, mental imagery, and other "tricks," could help him remember information. He also knew there were limits to what he could accomplish in the few hours he had to prepare for his exam. In fact, many aspects of Nate's own thinking—attention, memory, and even the fact that he could evaluate his thought capabilities—have been topics of great interest to developmental psychologists. In this chapter, we continue our examination of cognitive development, this time from an important alternative viewpoint to the perspectives described in the chapter titled "Cognition: Piaget and Vygotsky": the information-processing perspective. First, we will summarize the major features of this theoretical model. Then we will survey several topics that have been studied extensively from the stance of information-processing theory, including attention, memory, and problem solving.

The Information-Processing Approach

As we saw in the chapter titled "Themes and Theories," information-processing theorists believe that human cognition is best understood as the management of information through a system with limited space or resources. In the information-processing approach, mental processing is usually broken down into several components or levels of activity. For example, memory processes are often partitioned into *encoding, storage,* and *retrieval* phases. Information is assumed to move forward through the system, and each stage of processing takes some time (Massaro & Cowan, 1993; Palmer & Kimchi, 1986).

Many traditional information-processing models are called **multistore models** because they posit several mental structures through which information flows

multistore model Information-processing model that describes a sequence of mental structures through which information flows.



Source: Adapted from Atkinson & Shiffrin, 1968.

FIGURE 9.1
A Schematic Model of Human Information Processing

This highly simplified model includes several cognitive structures and processes that many information-processing theorists believe to be important in cognitive development. As the arrows indicate, information often flows in several directions between various structures. The goal of information-processing models is to identify those structures and processes that are at work when a child responds to his or her environment.

sequentially, much as data pass through a computer. One example of this type of model is shown in Figure 9.1. Most multistore models distinguish between psychological structures and control processes. *Psychological structures* are analogous to the hardware of a computer. The *control processes* are mental activities that move information from one structure to another, much as software functions for the computer.

Suppose someone asks you to repeat a list of words, such as *shoe, car, truck, hat, coat, bus*. If you have paid attention to all of the words and, like an efficient computer, "input" them into your cognitive system, processing will begin in the **sensory register.** Information is held here for a fraction of a second in a form very close to the original stimuli, in this case the audible sounds you experienced. Next, the words may move to the *memory stores.* **Working memory** (sometimes called *short-term memory*) holds information for no more than a couple of minutes. Many researchers consider working memory to be a kind of work space in which various kinds of cognitive tasks can be conducted. If you were to repeat the words over and over to yourself—that is, rehearse them—you would be employing a *control process* to retain information in working memory. You might also use the second memory store, **long-term memory,** the repository of more enduring information, and notice that the items belong to two categories, clothing and vehicles. The *executive control* oversees this communication among the structures of the information-processing system. Finally, when you are asked to say the words aloud, your *response system* functions to help you reproduce the sounds you heard moments earlier.

Other theorists in this field have advanced a **limited-resource model** of the cognitive system that emphasizes a finite amount of available cognitive energy that can be deployed in numerous ways, but only with certain tradeoffs. Limited-resource models emphasize the allocation of energy for various cognitive activities rather than the mental structures themselves. The basic assumption is that the pool of resources available for processing, retaining, and reporting information is finite (Bjorklund & Harnishfeger, 1990). In one such model, introduced in the chapter titled "Cognition: Piaget and Vygotsky," Robbie Case proposes an inverse relationship between the amount of space available for operating on information and that available for storage (Case, 1985; Case, Kurland, & Goldberg, 1982). *Operations,* as we have seen,

sensory register Memory store that holds information for very brief periods of time in a form that closely resembles the initial input.

working memory Short-term memory store in which mental operations such as rehearsal and categorization take place.

include processes such as identifying the stimuli and recognizing relationships among them; *storage* refers to the retention of information for use at a later time. If a substantial amount of mental effort is expended on operations, less space is available for storage or retention.

In the simple memory experiment we just examined, the effort used to identify the words and notice the categorical relationships among them will determine the space left over for storing those words. If we are proficient at recognizing words and their relationships, storage space will be available. If these tasks cost us substantial effort, however, our resources will be taxed and little will be left for the task of remembering. Robert Kail's research (1986, 1991a, 1991b) supports the idea that a central component of cognitive development is an increase in processing speed with age. As children grow older, they can mentally rotate images, name objects, or add numbers more rapidly. More resources then become available for other cognitive tasks.

How do these two general information-processing frameworks, the multistore model and the limited-resource model, account for cognitive development? Multistore models allow for two possibilities. Changes in cognition can stem from either an increase in the size of the structures—the "hardware"—or increasing proficiency in employing the "software," or control processes. For example, the capacity of the mental structure working memory may increase with age, or, as children grow older, they may increase their tendency to rehearse items to keep information in working memory or even push it into long-term memory. Limited-resource models suggest that what changes during development is processing efficiency. As children become more proficient in manipulating information, more internal space is freed up for storage.

The Development of Attention

Have you ever noticed that sometimes a teenager can spend hours absorbed in a single activity, such as doing a jigsaw puzzle or playing a video game, whereas a toddler seems to bound from activity to activity? Most of us have a sense that older children are better able than younger ones to "pay attention" to a given task. Researchers have documented how children's attentional processes undergo recognizable changes with development.

Attention has been conceptualized as a process that allows the individual to focus on a selected aspect of the environment, often in preparation for learning or problem solving (Kahneman, 1973). Attention represents the first step in cognitive processing and, as such, is a critical phase. Unless information enters the system in the first place, there will be few opportunities to develop memory, concepts, or other cognitive skills. Children with a poor capacity to attend will have difficulties in learning, the ramifications of which can be enormous, especially as they enter school. Research evidence corroborates that children who have greater attention spans and persistence in tasks at ages four to five years have higher intelligence scores and school achievement by the time they get to second grade (Palisin, 1986). Even at three months of age, infants who pay greater attention to stimuli have better recognition memory for them (Adler, Gerhardstein, & Rovee-Collier, 1998).

Sustaining Attention

One of the most obvious developmental trends is the dramatic increase in the child's ability to *sustain* attention on some activity or set of stimuli. Holly Ruff and Katharine Lawson (1990) observed one-, two-, and three-and-a-half-year-olds while the children played with an array of six toys. They observed a steady increase with age in the amount of attention directed to individual toys. On average, one-year-olds showed focused attention for 3.33 seconds, two-year-olds for 5.36 seconds, and three-and-a-half-year-olds for 8.17 seconds. Generally, at ages two and three, children

long-term memory Memory that holds information for extended periods of time.

limited-resource model Information-processing model that emphasizes the allocation of finite energy within the cognitive system.

show longer periods of attention to television and to toys they are playing with than to highly structured tasks. Between ages three and five years, though, children show growth in the ability to attend to tasks arranged by an adult (Ruff, Capozzoli, & Weissberg, 1998). The attention span continues to increase throughout the early school years and adolescence and shows a particularly marked improvement around age ten years (Milich, 1984; Yendovitskaya, 1971).

KEY THEME
Interaction Among Domains

Why does sustained attention increase with age? Maturation of the central nervous system is partly responsible. The reticular activating system, the portion of the lower brainstem that regulates levels of arousal, is not fully mature until adolescence. Another factor may be the increasing complexity of the child's interests. Young children seem to be intrigued by the physical properties of objects, but because these are often not too complex, simply looking at or touching objects quickly leads to habituation. On the other hand, older children are more concerned with creative and varied ways of playing with objects (Ruff & Lawson, 1990). As children actively generate more possible uses for stimuli, their active engagement with stimuli captivates and feeds back to influence attention.

KEY THEME
Child's Active Role

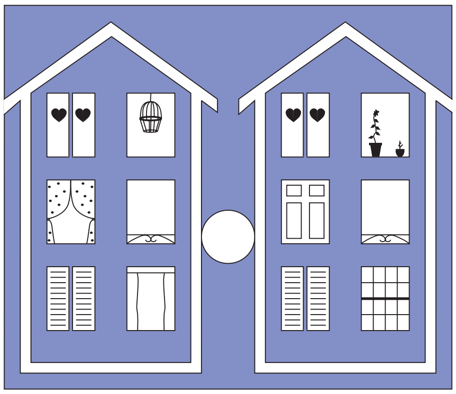
Deploying Attention

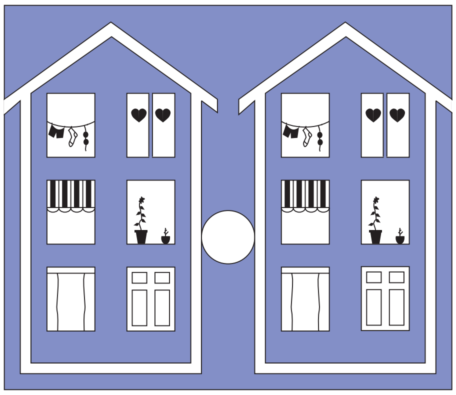
A second developmental change in attentional processes involves the ability of children to control their attention in a systematic manner; that is, they increasingly *deploy* their attention effectively, such as when they are comparing two stimuli. At three-and-a-half months of age, shifts of attention from one stimulus to another appear to be reflexive in nature, but by five to six months of age, they are more deliberate and planned. Changes in the electrical activity of the cortex accompany this changeover to more controlled attention (Richards, 2000). During the period from about five to seven months, infants also exhibit a marked increase in the rate with which they shift attention from one stimulus to another. More rapid shifts probably reflect the infant's greater efficiency in processing information from the environment. Researchers hypothesize that the infant's ability to *inhibit* processing of one stimulus so that the next one can be attended to underlies more rapid shifts (Rose, Feldman, & Jankowski, 2001a).

The classic studies of Eliane Vurpillot (Vurpillot, 1968; Vurpillot & Ball, 1979) illustrate developmental changes in how older children control their attention. Children were shown a picture of two houses, each having six windows, and were asked to judge whether the houses were identical (see Figure 9.2). As they inspected the houses, their eye movements were filmed. Preschoolers scanned the windows less thoroughly and systematically than older children. For example, when the houses were identical, four- and five-year-olds looked at only about half of the windows

FIGURE 9.2
Comparing Houses

Children were asked to explore houses to make judgments about whether they were the same or different while a camera photographed their eye movements. Preschoolers explored the windows less thoroughly, efficiently, and systematically than older children.





Source: Adapted from Vurpillot, 1968

before making a decision, but older children looked at nearly all of them. When the windows differed, older children were more likely than younger children to stop scanning as soon as they detected a discrepancy. Finally, older children were more likely to look back and forth at windows in the same locations of the two houses; younger children displayed more haphazard fixations, looking at a window in one house, then a different window in the other house.

In another experiment, Patricia Miller and Yvette Harris (1988) found that children not only become more systematic but also use more *efficient* attentional strategies as they grow older. Preschoolers were asked to determine whether one row of six drawings of toys contained the same elements in sequence as a second row of six drawings. To accomplish this task, they had to open doors that covered the pictures. Three-year-olds tended to be systematic but not very efficient: they opened one entire row first, then opened the next row. In contrast, four-year-olds adopted a systematic and more efficient strategy for comparing: they opened each vertically aligned pair from one end of the array to the next. Perhaps as a consequence, the older participants were more accurate in their judgments about whether or not the rows were identical.

Selective Attention

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Testing Selective Attention

Still another aspect of attention that changes with development is the ability to be *selective*. Older children are much more likely than younger children to ignore information that is irrelevant or distracts from some central activity or problem. For example, in one study children ages six, nine, and twelve years participated in a *speeded classification task*. They were given decks of cards that varied on one or more stimulus dimensions: form (circle or square), orientation of a line (horizontal or vertical), and location of a star (above or below the center). The objective was to sort the cards on the basis of one predetermined dimension as quickly as they could. But what happened when an irrelevant dimension was added to the cards in the deck? This manipulation interfered with the ability of six-year-olds to sort the cards but had little effect on the performance of older children (Strutt, Anderson, & Well, 1975). Other research confirms that the ability to filter out distracting information continues to mature at least until early adolescence (Goldberg, Maurer, & Lewis, 2001).

KEY THEME
Interaction Among Domains

The ability to attend to some parts of an event or activity to the exclusion of others signals the child's increasing skill at controlling his own cognitive processing. This ability likely depends to some extent on the maturation of the prefrontal cortex, which we know is involved in selective attention in adults (Husain & Kennard, 1997). Also contributing to this change is the child's growing understanding that his attentional capacity is limited and that cognitive tasks are best accomplished with focused attention. Growth in this knowledge occurs during the preschool and early school years. When asked if they would rather listen to pairs of stories simultaneously or one at a time, three-year-olds are willing to listen to two tape recordings at once, but four-year-olds prefer to listen to one at a time (Pillow, 1988). Six-year-olds state that a person who is concentrating on one task will not pay much attention to other things, whereas four-year-olds do not exhibit this understanding (Flavell, Green, & Flavell, 1995).

KEY THEME
Sociocultural Influence

To some degree, the child's knowledge about attention may be gleaned from the kinds of behaviors that are emphasized in his or her culture. In our society, focusing on one thing at a time is probably considered by most parents and teachers to be a desirable goal (Ruff & Rothbart, 1996). However, this pattern is not universal. Among members of a Mayan community in Guatemala, both toddlers and caregivers spend more time attending simultaneously to several competing events—an interesting toy and a playful sibling, for example—than American children and caregivers (Chavajay & Rogoff, 1999). Cultural preferences may thus guide the particular attentional style a child develops.

ATYPICAL DEVELOPMENT

Attention Deficit Hyperactivity Disorder

Between 3 and 5 percent of school-age children in the United States, usually boys, show a pattern of impulsivity, high levels of motor activity, and attention problems called *attention deficit hyperactivity disorder* or *ADHD* (American Psychiatric Association, 2002). The disorder is puzzling because its cause is not completely understood, and an unambiguous diagnosis can be difficult to obtain. At the same time, for parents, teachers, and the children themselves, the consequences of the disorder—poor school achievement, behavior management problems, poor peer relationships, negative moods, and low self-esteem among them—can be serious (Erhardt & Hinshaw, 1994; Rapport, 1995; Whalen et al., 2002). Whereas hyperactivity and impulsivity may decline in adolescence, problems with attention often persist for years (Hart et al., 1995).

As the diagnostic label implies, a major assumption about the nature of ADHD is that these children have some type of deficit in attention. But what precisely is the nature of that deficit? A prominent current hypothesis is that children with ADHD have problems with higher-order executive control processes, especially those that help children to inhibit their tendencies to respond (Barkley, 1997; Pennington, 1998). In one type of experiment, children sitting in front of a computer screen are instructed to hit one key if they see the letter "X" appear and to hit another key if the letter "O" pops up. However, if they first hear a tone, they must not hit a key at all. Children with ADHD have difficulty stopping themselves unless the tone is played much earlier than the letter appears (Schachar et al., 2000).

Children with ADHD also have difficulty in being selective when confronted with numerous stimuli that compete for their attention. An experiment comparing six- to twelve-year-old ADHD boys with non-ADHD boys as they watched television demonstrates this effect (Landau, Lorch, & Milich, 1992). Each boy watched four segments of a show for fourteen minutes, half the time with several distracting toys in the room and half the time without toys. All participants were told they would have to answer some questions about the televised segments at the end of the viewing period. When distracting toys were present, ADHD boys paid about half as much attention to the shows as the non-ADHD boys. However, the two groups did not differ in their attention in the absence of distracting toys. These results suggest that ADHD children do not have a pervasive problem in sustaining attention; rather, they have difficulty in the presence of extraneous stimulation.

Some researchers now hypothesize that the specific cognitive problem that children with ADHD have is with working memory, the memory store in which "cognitive work" occurs (Tannock & Martinussen, 2001). In this line of thinking, the process of selective attention takes place in working memory. A recent study showed that normal adults, too, are distracted by stimuli when they are overloaded with another demanding cognitive task, such as remembering a set of digits. When less stress is placed on the cognitive system, problems in attention diminish (de Fockert et al., 2001).

KEY THEME
Nature/Nurture

Why do children with ADHD have these difficulties? Several studies implicate biological factors. Individuals with ADHD show abnormal brain wave activity, slower blood flow, and lower glucose metabolism in the prefrontal regions of the brain that are associated with regulating attention and motor activity (Rapport, 1995). Also, several brain regions, including the prefrontal cortex, are smaller in children with ADHD than in children without the diagnosis (Giedd et al., 2001). Evidence also indicates that ADHD may have an inherited component. In one investigation, 65 percent of the ADHD children in the sample had at least one relative with the disorder (Biederman et al., 1990). Other risk factors for attention problems include prenatal exposure to alcohol (Streissguth et al., 1995) and possibly nicotine, cocaine, or other drugs that may affect the developing brain of the fetus (National Institute of Mental Health, 1996).

ADHD children are frequently treated with medications, such as Ritalin, that are classified as stimulants but that actually serve to "slow them down." This treatment helps many children, as does a combination of medication and behavior therapy, according to a major national study conducted by the National Institute of Mental Health (MTA Cooperative Group, 1999). But some experts worry that too many children are placed on this medication simply because they exhibit behavior problems rather than genuine ADHD. Clearly, a better understanding of ADHD is needed to sharpen its clinical diagnosis and develop effective treatment strategies for these children.

FOR YOUR REVIEW

- What are the major differences between multistore and limited-resource models of information processing? How do they differ in accounting for developmental changes in cognition?
- What are three major ways in which attention changes with development?
- What factors seem to be responsible for developmental changes in attention?
- What is ADHD? What factors may be responsible for its occurrence?

The Development of Memory

Few cognitive skills are as basic as the ability to store information encountered at a given time for potential retrieval seconds, minutes, days, or even years later. It is hard to imagine how any other cognitive activity, such as problem solving or concept formation, could take place without the ability to draw on previously experienced information. How could we classify dogs, horses, and giraffes into the category "animals" without remembering the shared features of each? How could we solve a problem such as Piaget's pendulum task, described in the chapter titled "Cognition: Piaget and Vygotsky," without remembering the results of each of our mini-experiments with the length of the string, weight of the object, and so on? In one way or another, memory is a crucial element in most of our thinking.

However, memory is far from a simple or unitary construct. One distinction is drawn between episodic and semantic memory. **Episodic memory** is memory for events that occurred at a specific time and place in the past ("What did you do on your first day of school?"). **Semantic memory,** on the other hand, consists of general concepts or facts that are stored without reference to a specific previous event ("How many inches are there in a foot?"). We can make another distinction, one between recognition and recall memory. Tasks that measure **recognition memory** require participants to indicate whether they have encountered a picture, word, or other stimulus before ("Have you seen this picture on previous trials of this experiment?"). Participants are required merely to give a *yes* or *no* answer or some other simple response that signals they have previously encountered an item. In **recall memory** tasks, participants must reproduce previously presented stimuli ("Tell me the twelve words you heard me say a few minutes ago."). The fact that memory can be conceptualized in such different ways has complicated the task of describing developmental processes. Nevertheless, three decades of research on this aspect of cognition have begun to suggest some clear and predictable trends in the development of memory.

episodic memory Memory for events that took place at a specific time and place.

semantic memory Memory for general concepts or facts.

recognition memory Ability to identify whether a stimulus has been previously encountered.

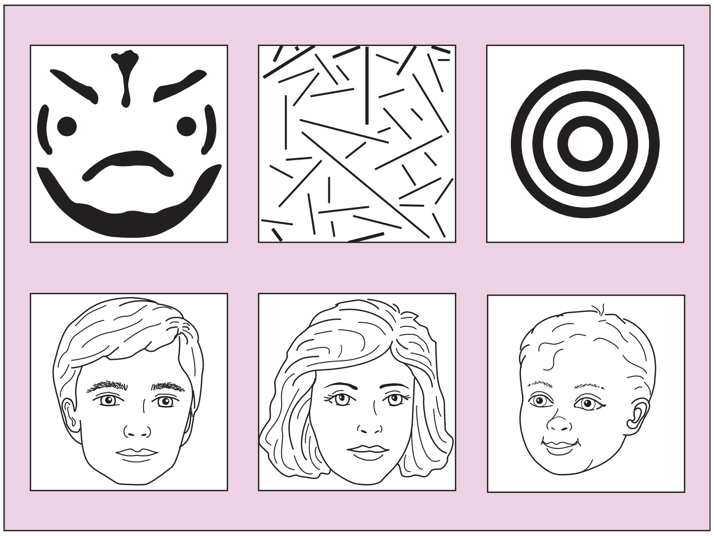
recall memory Ability to reproduce stimuli that one has previously encountered.

Recognition Memory

How early can we demonstrate the presence of memory? How long do those memories last? How much information can be retained through recognition memory? Two techniques useful in documenting young infants' perceptual abilities and discussed

FIGURE 9.3
Infant Recognition Memory

Fagan tested infant recognition memory by using visual stimuli in a paired-comparison procedure. For each row, one of the stimuli was presented repeatedly until habituation occurred. Then one of the other stimuli in the row was paired with the familiar stimulus to see if infants preferred the novel item. Infants only a few months old looked longer at novel items up to fourteen days after the initial familiarization.



Source: Adapted from Fagan, 1974.

in the chapter titled "Basic Learning and Perception," *habituation* and *operant conditioning,* have also been fruitful in yielding answers to these questions about infants' and young children's recognition abilities.

Much of the earliest research on infant recognition memory was conducted by Joseph Fagan, who used the habituation procedure. First, a visual stimulus such as a photograph of a human face or a geometric figure (some examples are shown in Figure 9.3) is presented to the infant for a predetermined period of time. On a subsequent trial, the same stimulus is paired with a completely new item, and the time the infant spends looking at each picture is recorded. In this *paired-comparison procedure,* infants typically look longer at the novel stimulus than at the familiar one, suggesting that they remember the familiar item. Using this basic approach, Fagan (1974) demonstrated that five- to six-month-olds familiarized with black-and-white photos of human faces for only a few minutes retain information about them for surprisingly long periods of time. When the recognition test occurred three hours or up to fourteen days after the initial familiarization, infants showed consistently longer visual fixations to the novel stimulus. This is an impressive level of performance for infants only a few months old!

Carolyn Rovee-Collier and her colleagues have used a different technique, relying on operant conditioning to demonstrate infants' early memory capabilities (Rovee-Collier & Hayne, 1987; Rovee-Collier & Shyi, 1992). As shown in Figure 9.4, an infant lies in a crib with a ribbon running from his ankle to an overhead mobile. Within a few minutes, the infant recognizes the contingency between his foot kicks and the movement of the mobile; his rate of kicking increases dramatically. Suppose, however, that the mobile is removed from the crib for two weeks. When the mobile is reintroduced, does the infant remember that this is the object that he can move with a foot kick? The answer is yes: three-month-olds vigorously kicked when the familiar mobile was replaced over the crib but did not kick as much when a brand-new mobile was put in the same position (Enright et al., 1983).

These early memories are easily disrupted, however, by changes in the context of the task. Suppose an infant learns the original contingency between a foot kick and the movement of the mobile when she is in a playpen lined with a yellow cloth with green squares. Twenty-four hours later, the mobile is reintroduced, but this time the cloth liner is blue with red stripes. Now the infant does not show a memory for the previous day's events; she does not kick nearly as much as she did at the end of training the previous day (Rovee-Collier et al., 1992). Thus infants six months of age and under encode very detailed and specific information about an event, even when that information is not the central focus of attention. Put another way, infants will show

Source: Stricker et al., 2001.

FIGURE 9.4
Using Operant Conditioning to Study Early Memory

Infants in Rovee-Collier's studies had a ribbon attached between their feet and an interesting mobile overhead. Infants quickly learned that kicking made the mobile move. When the mobile was removed and then reintroduced after a delay interval, infants showed that they "remembered" it by vigorously kicking again.

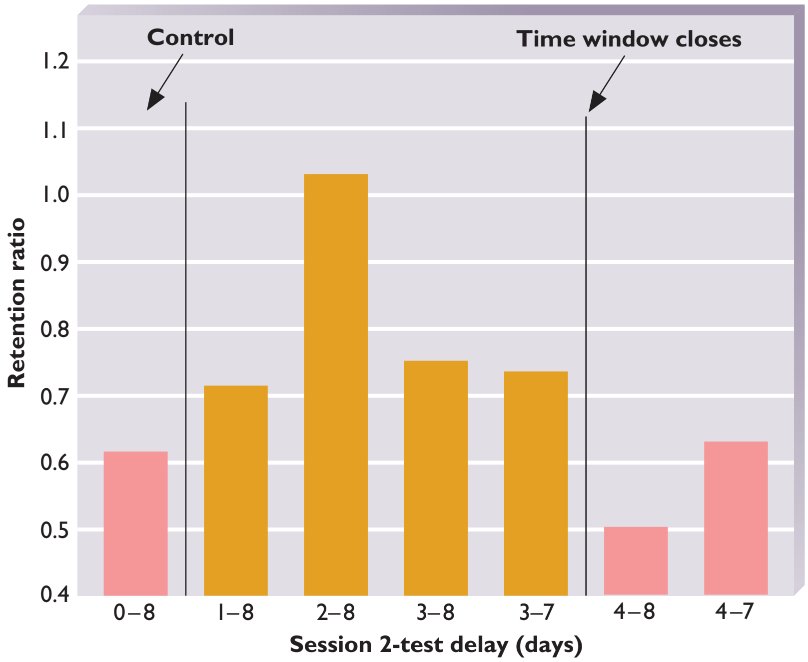
evidence of memory only when the conditions during training and memory testing are as similar as possible (Hayne & Rovee-Collier, 1995). By the latter portion of the first year, however, infants are more likely to disregard differences in contextual cues when they are tested for memory, perhaps because their memories are more robust (Hartshorn et al., 1998). More broadly speaking, they can remember things that are learned in one place and tested in another (Rovee-Collier, 1999). Thus recognition memory shows distinct developmental changes in the first year.

Reminders of an event can enhance infant recognition, but when they occur is apparently crucial. If infants who had learned to make a foot-kick in the presence of a mobile were given a "memory boost" by seeing the mobile again within three days, they showed memory for the mobile by kicking in its presence eight days later. Reminders given more than three days later did not have this effect; infants seemed to have forgotten the mobile at the eight-day test (Rovee-Collier, Evancio, & Earley, 1995). Figure 9.5 summarizes the results of this experiment. Rovee-Collier (1995) proposes that there are *time windows* within which a reminder can provide an "inoculation" against forgetting. Reminders toward the end of the time window rather than at its beginning seem to be especially effective (Rovee-Collier, Greco-Vigorito, & Hayne, 1993).

At just how young an age do infants display recognition memory? One experiment shows that even newborns can retain information for at least a twenty-four-hour period (Swain, Zelazo, & Clifton, 1993). On the first day of the study, newborns heard a tape of a word, either *beagle* or *tinder,* that was repeated during the experimental session while an observer recorded the number of head turns the infants made toward the sound. As you would expect with the habituation procedure, the number of head turns declined over the session. One day later, one group of infants heard the same word again, whereas a second, experimental group heard a new word.

FIGURE 9.5
Time Windows in Remembering

In an experiment conducted by Carolyn Rovee-Collier and her colleagues, three-month-old infants were trained to kick in the presence of a mobile. The numbers along the horizontal axis give the days on which the various components of the study occurred. Day 0 is the day of original training. Days 1–8 signifies that the reminder occurred one day after the initial training and the long-term memory test occurred on day 8 and so on. The graph shows that infants who had received a "reminder" of the event up to three days after the initial training had improved memories.



Source: Rovee-Collier, Evancio, & Earley, 1995
Note: The retention ratio on the vertical axis is a mathematical measure of how much infants remembered. It is the proportion of training kicking rate that infants displayed during the long-term memory test.

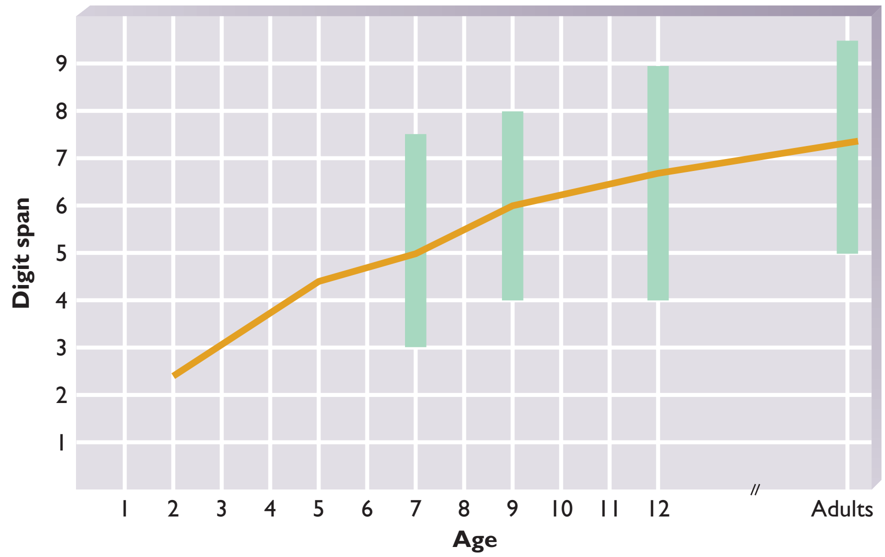
Infants in the first group made fewer head turns toward the stimulus word and more head turns away from it than infants in the second group. Evidently, they remembered some very specific properties of the auditory stimulus for a duration of many hours.

How many items can infants remember? Susan Rose and her colleagues found that at five to seven months of age, infants had trouble recognizing a string of three or four different objects that were presented as part of one memory trial but that, by twelve months of age, almost half of infants were successful (Rose, Feldman, & Jankowski, 2001b). Older infants and preschool-age children are even more impressive. Typically, researchers present children with a large number of pictures, sometimes as many as one hundred. On test trials, the "old" pictures are interspersed with "new" ones, and children state whether they had seen the picture before. Alternatively, researchers note whether children look longer at the novel pictures. In general, children correctly recognize a striking percentage—75 percent or more—of stimulus items even when they are tested several weeks later (Brown & Scott, 1971; Daehler & Bukatko, 1977).

Finally, recent studies that measure brain wave activity as individuals respond to old and new stimuli indicate that the speed of recognition memory, as well as its accuracy, increases from the preschool years to young adulthood (Cycowicz et al., 2001; Marshall et al., 2002). Thus, although recognition memory is present from the child's earliest hours, age-related changes are seen in some of its characteristics.

Recall Memory

Researchers have used different types of tasks to assess the development of recall memory. Some of these tasks have been focused on short-term memory, whereas others have tapped memories over longer durations. Regardless of the delay period involved, the child's use of memory strategies seems to be an important factor in preserving past events. However, alternative conceptualizations of memory development emphasizing different aspects of processing have also offered explanations of memory improvement.



Source: Adapted from Dempster, 1981.

FIGURE 9.6 Developmental Changes in Memory Span

In the memory span task, participants are asked to repeat a string of digits after an interval of a few seconds. The points on the curve represent the average number of digits participants are able to recall. The bars represent the ranges of typical performance at each age. Memory span increases throughout childhood and approaches the adult level between ages ten and twelve years.

Memory Span Suppose someone asks you to repeat a string of digits, such as a phone number. Like most adults, you should be able to repeat between seven and nine digits with relatively little difficulty as long as no more than approximately thirty seconds elapse after you first hear the digits. Tasks such as these measure **memory span,** the number of stimulus items that can be recalled after a brief interval. Children under age ten years remember fewer items than do adults. As Figure 9.6 shows, two-year-olds typically remember only about two items, four-year-olds about three or four, and seven-year-olds about five (Dempster, 1981).

Do these changes in memory span occur because the storage capacity of memory increases? Numerous memory experiments suggest that this is not necessarily the case. Instead, children's ability to employ **memory strategies,** activities to enhance the encoding and retrieval of information, increases with age. Children seven years and older are more likely than younger children to rehearse items or reorganize them into more meaningful, and hence more memorable, units. For instance, noting that the numbers 1, 3, 5, and 7 form the sequence of odd numbers makes the list easier to recall. So does simply repeating them over and over. Alternatively, as we saw at the start of this chapter, Robbie Case and his colleagues have proposed that increases in memory span can be understood as a result of the increasing operational efficiency children display as they mature (Case et al., 1982). As operational efficiency increases, more cognitive resources are available for storage.

KEY THEME
Child's Active Role

Changes in **processing speed,** the rapidity with which cognitive activities are carried out, indeed contribute to developmental gains in memory span. Researchers have suggested that two types of processing speed are important. Among children ages seven to eight, the ability to speak digits or words rapidly—presumably indexing the *rate of verbal rehearsal*—is related to their memory span. Among children ages eleven and twelve, memory span is more closely linked to shorter silent pauses between the items as they are being recalled. This second measure is presumed to index the rate at which items are actually *retrieved* from short-term memory. The data suggest that these different aspects of processing speed mature at different ages (Cowan, 1999; Cowan et al., 1998).

The memory span task is usually believed to tap short-term memory because the interval between presentation of the stimuli and the memory test is relatively brief. Other techniques have been used to study the ability of children to remember lists of words, sentences, or other items for longer than a few seconds.

memory span Number of stimulus items that can be recalled after a brief interval of time.

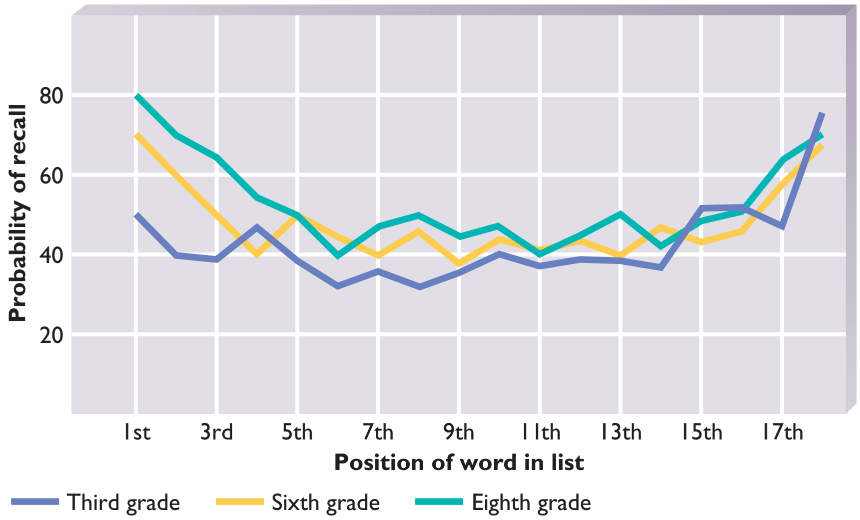
memory strategy Mental activity, such as rehearsal, that enhances memory performance.

processing speed The rapidity with which cognitive activities are carried out.

Elicited Imitation Suppose you want to study recall from long-term memory, but the child you are studying does not yet speak. How can you find out about his or her

FIGURE 9.7
Developmental Differences in Free Recall

This graph shows the probability that a word will be recalled by third-, sixth-, and eighth-graders in a free-recall task. Few developmental differences appear in memory for the last few items in the list, but older children show elevated levels of recall for the first few items. This pattern suggests that older children are more likely than younger children to employ memory strategies such as rehearsal to remember the early items.



Source: Adapted from Ornstein, Naus, & Liberty, 1975.

memory skills? In the chapter titled "Basic Learning and Perception," you learned about a technique called *deferred imitation,* in which infants are shown a unique sequence of actions and then observed to see whether they imitate those behaviors at a later time. For example, in Andrew Meltzoff's studies, infants typically see the experimenter pull the square ends off a dumbbell or push a button on a box with a stick. When tested as long as four months later, a substantial number of fourteen-month-olds remembered the specific action sequences (Meltzoff, 1995).

Similarly, Patricia Bauer and her colleagues have used a procedure they call **elicited imitation,** in which older infants and preschoolers must repeat a sequence of actions demonstrated by the experimenter. For example, one sequence used in these studies is "making a gong." Children watch as the researcher shows three distinct steps to an event they have never seen before: (1) putting a bar across two posts; (2) hanging a plate from the bar; and (3) hitting the plate with a mallet. Then, weeks or even months later, the children return to the laboratory and are asked to repeat the sequence of actions with the array of parts they see on the table. In other words, they must recall a correctly ordered set of behaviors after a long delay.

Bauer's studies show that by the time most children start their second year, they need to see the sequence only once in order to remember it one month later. By twenty months of age, memories for the sequence last for as long as twelve months (Bauer, 2002; Bauer et al., 2000). These studies provide dramatic evidence for the presence of recall memory well before children have developed their language skills.

● **Free Recall** Many studies of memory with older children have used *free-recall* tasks in which they are given a list of words or objects that they are to repeat, after a specified delay period, in any order they wish. As Figure 9.7 shows, few developmental differences in recall are usually noted for items later in the list (Ornstein & Naus, 1978; Ornstein et al., 1975). Children of all ages recall these items well, at least by the time they are of elementary school age. This elevated recall for later items, called the **recency effect,** is viewed as the extraction of information from more immediate memory, a task that is usually not too demanding for children age four years and older. Older children, however, show a clear advantage for recalling items that appeared in the early or middle positions in the list. The fact that older children show good memory for early items is called the **primacy effect.** Developmental differences in the primacy effect can be explained as the result of the tendency of older children, those age seven years or older, to engage in deliberate strategies to improve recall. They repeat items aloud, make up sentences connecting the items, or think of mental images that connect the items. In fact, much of the research on memory development has centered on detailing the types of strategies children of different ages display.

elicited imitation A way of assessing memory in which children must reconstruct a unique sequence of actions that they have seen in the past; usually used with preverbal children.

recency effect Tendency for individuals to show good recall for the last few items in a list.

primacy effect Tendency for individuals to display good recall for early items in a list.

Memory Strategies How do you make sure you remember your grocery list or where you hung your coat in a restaurant coatroom? Or, as in the case of Nate, the underprepared student described at the beginning of the chapter, how do you make sure you remember important facts and concepts for a test in school? Ordinarily, you must perform some activity to ensure that the stimuli are correctly and enduringly encoded in the first place. As a mature rememberer, you often capitalize on cues that may later "trigger" retrieval. Thus, you might say the words in your grocery list over and over to yourself ("milk, eggs, bread; milk, eggs, bread") or note the characteristics of the location of an object ("I hung my coat next to the bright red one"). In general, as children grow older, they become more likely to employ self-generated strategies for both encoding and retrieval and to take advantage of external information that can potentially aid recall.

KEY THEME
Child's Active Role

We already identified one useful memory tactic, **rehearsal**—simply repeating, either aloud or silently, items to be remembered. The fact that young children are unlikely to engage spontaneously in rehearsal is well documented. In a study mentioned in the chapter titled "Language," investigators asked kindergartners, second-graders, and fifth-graders to observe as an experimenter pointed to three specific pictures in an array of seven (Flavell, Beach, & Chinsky, 1966). When asked to point to the same sequence after a fifteen-second delay, fifth-graders showed significantly greater accuracy than the other two age groups. More important, during the delay period the researchers recorded any signs that the children may have been rehearsing the items to be remembered, such as moving their lips or vocalizing to themselves. They found that 85 percent of the fifth-graders engaged in spontaneous rehearsal, whereas only 10 percent of the kindergartners did. Moreover, children who rehearsed showed the best recall. In other words, there was a direct link between the children's production of this strategy and memory performance.

Older children also exhibit another important memory strategy called **organization,** the tendency to reorder items to fit some category or higher-order scheme. If the items to be recalled can be grouped conceptually, older children do so, and the amount they recall increases accordingly. For example, if the stimulus list contains words from the categories *animals, furniture, vehicles,* and *clothing* (e.g., *sofa, dog, chair,* etc.), ten- and eleven-year-olds spontaneously cluster conceptually related items together as they recall them, whereas five- and six-year-olds do not (Moely et al., 1969). Furthermore, instructing children to group the words or objects they are to remember into categories significantly enhances recall (Bjorklund, Ornstein, & Haig, 1977; Black & Rollins, 1982).

Still another helpful memory technique is the use of **elaboration,** thinking of a sentence or an image that links together items to be remembered. If you have to remember the list *cat, shoe, piano,* you might construct the sentence "The cat wearing shoes played the piano" or think of a visual image portraying this scene. Elaboration is one of the latest memory strategies to appear; usually children do not spontaneously use images or elaborative verbalizations until adolescence or later (Pressley & Levin, 1977).

The strategies just discussed pertain mostly to *encoding*, or getting information into the memory stores; but older children are also better at *retrieval*, or getting it out. Figure 9.8 shows the sketches made by a first-grader and a seventh-grader who were asked in one recent study to "write or draw anything you want to help you win the game" as they played the memory game "Concentration." Notice how the first-grader's drawing has little to do with the game; it is simply a picture depicting an unrelated event. In contrast, the seventh-grader's notations contain important details about what the items are and their specific locations on the game board. Not surprisingly, the results of the study showed that the better the quality of children's notations, the fewer turns it took for them to win the game (Eskritt & Lee, 2002).

Throughout this discussion, the recurring theme has been the tendency of children over seven years of age to initiate some activity that will improve their recall. Younger children, however, are not completely deficient in the use of strategies. For example, when preschoolers are instructed to "remember" a set of objects, they are

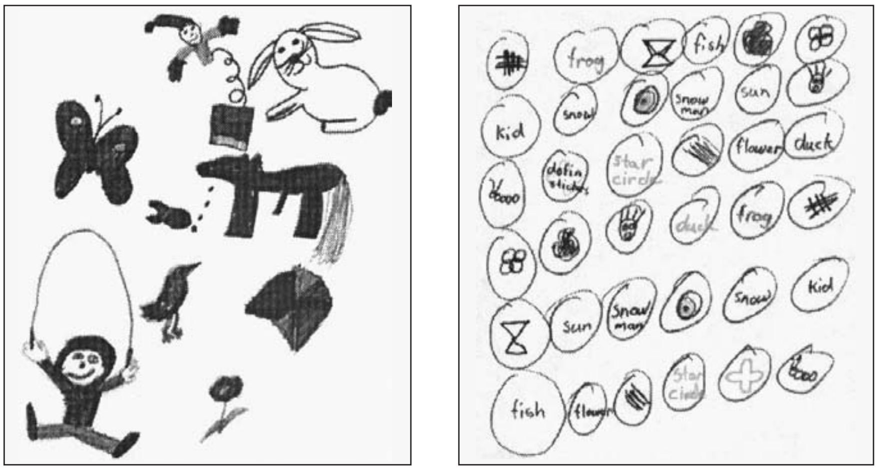
rehearsal Memory strategy that involves repetition of items to be remembered.

organization Memory strategy in which individuals reorder items to be remembered on the basis of category or some other higher-order relationship.

elaboration Memory strategy in which individuals link items to be remembered in the form of an image or a sentence.

FIGURE 9.8
Generating Retrieval Cues for Memory

Older children are more skilled than younger children at producing notes to help them to remember information. The drawing on the left was made by a first-grader playing a memory game. The items in this child's drawing have little to do with the stimulus items to be remembered. In contrast, the seventh-grader's notations on the right include the stimulus items themselves, as well as their specific locations. Children who produce good external notes are more successful in memory tasks.



Source: Eskritt & Lee, 2002.

more likely to name and look at them than children who are instructed to "play with" the objects (Baker-Ward, Ornstein, & Holden, 1984). However, younger children do not generate memory strategies such as rehearsal or organization on their own, a phenomenon termed **production deficiency** (Flavell, 1970). It is important to note that when younger, nonstrategic children are instructed to employ strategies, their recall markedly improves (Keeney, Cannizzo, & Flavell, 1967; Moely et al., 1969; Ornstein & Naus, 1978). The only exception appears to occur when children are first learning a strategy; there seems to be a transition time during which younger children's recall does not improve substantially when they first employ a memory strategy, a phenomenon called **utilization deficiency** (Miller, Woody-Ramsey, & Aloise, 1991). Recent research has also revealed that children sometimes use multiple strategies—not just one—while engaged in a memory task, employing a mix of rehearsal and organization, for example (Coyle & Bjorklund, 1997). Thus development is not characterized by the replacement of simple strategies such as rehearsal with more sophisticated ones such as organization. Instead, the array of study techniques available to children seems to expand with development.

How can we explain children's tendency to become more strategic and able to plan with age? Parents play at least a partial role. Hilary Ratner (1984) found a positive relationship between three-year-olds' memory performance and the frequency with which their mothers asked them questions about past events, such as "Where did you put your coat?" or "What does an airplane do?" Such memory demands may help children learn about encoding and retrieval processes that aid memory. Children may also learn to use strategies indirectly from environments that provide information in an organized, structured way (Ornstein, Baker-Ward, & Naus, 1988). For example, teachers usually present lessons in a cohesive, integrated manner. Pupils who have this repeated experience may discover on their own memory strategies they can apply to other situations.

production deficiency Failure of children under age seven years to spontaneously generate memory strategies.

utilization deficiency Phenomenon by which a memory strategy, when first applied, may fail to improve memory in a noticeable way.

metamemory Understanding of memory as a cognitive process.

● **Controlling Cognitive Processing** Until recently, most explanations of developmental changes in memory have focused on children's increasing use of deliberate strategies to enhance their recall. However, theorists now recognize that this focus does not capture the full complexities of cognitive processing in children. Developmental changes in memory are now understood in terms of the child's increasing efficiency and control over cognitive processes.

Metamemory, the child's understanding of memory, is one aspect of this process. It includes the ability to assess one's own memory characteristics and limitations, the demands made by different memory tasks, and the strategies likely to benefit memory (Flavell & Wellman, 1977; Guttentag, 1987). It also includes the ability to monitor the contents of one's own memory and to make decisions about how to allocate cognitive resources ("Have I memorized everything thoroughly? Do I still need to study some items?") (Kail, 1990). Advances in each of these aspects of metamemory are, to some degree, related to improvements in memory as children get older. For example, older children have a better understanding than younger children that longer lists are harder to remember than shorter ones and that events from the distant past are more difficult to remember than more recent events (Kreutzer, Leonard, & Flavell, 1975; Lyon & Flavell, 1993; Wellman, 1977). One consequence of this awareness is that children begin to see the need to use strategies (Schneider, 2000).

KEY THEME
Child's Active Role

The child also displays a growing ability to engage in *cognitive inhibition*, to regulate how much irrelevant information gets processed. Older children are better able than younger children to filter out information that is not pertinent to the task at hand so that the space allocated to cognitive processing is greater. For example, older children can selectively forget irrelevant information; they can intentionally keep it "out of mind" (Harnishfeger & Pope, 1996; Pope & Kipp, 1998). Accomplishments like these are good examples of the child's increasing control over the management of his own thinking.

Charles Brainerd and Valerie Reyna's *fuzzy trace theory* (Brainerd & Gordon, 1994; Reyna & Brainerd, 1995) provides still another example of growing cognitive efficiency. According to this theory, a continuum exists for how literally memories are stored. On one end, memories are very true to the original event, containing verbatim information. On the other end, they may be stored as "fuzzy traces" or "gists," containing the essence or core of the event without the literal details. Both types of memory representations coexist, but they are used for different purposes. Gists, according to this theory, are extracted by children of all ages, but younger children are more predisposed toward verbatim memories. Difficulties can arise, though, because verbatim memories are more vulnerable to disruption; they also make more demands on the cognitive system in that they take more time to process. Young children's performance is affected by these demands.

To illustrate this theory, consider a study in which preschoolers and second-graders were given the following problem: "Farmer Brown owns many animals. He owns three dogs, five sheep, seven chickens, nine horses, and eleven cows." Children were then asked verbatim questions such as, "How many chickens does Farmer Brown own, seven or five?" or gist questions such as, "Does Farmer Brown have more cows or horses?" Among preschoolers performance was better on the verbatim questions than the gist questions, whereas the reverse was true for the second-graders. In addition, preschoolers and second-graders performed at equal levels on the verbatim questions, but second-graders had better recall for the gist questions (Brainerd & Gordon, 1994). Children who can focus on the gist of information do not get distracted by irrelevant details and retain the core of essential information for longer periods of time.

● **Memory and the Growth of General Knowledge** Do younger children ever remember more than older children or adults? In a unique experiment, Michelene Chi (1978) found that in certain situations they do. Adults and children averaging ten years of age were asked to remember lists of ten digits presented by the experimenter. Typically, the adults' performance surpassed the children's. However, when the memory task consisted of reproducing chess positions previously seen for only ten seconds on a chessboard, children significantly outperformed adults. How did they accomplish this remarkable feat? Chi explains that the children who participated were experts in the game of chess, whereas the adults (who were college educated) had only casual knowledge of the game. By having greater knowledge, these children probably could encode the familiar patterns of chess pieces more efficiently, whereas adults were probably seeing random arrangements of rooks, knights, and pawns. Thus, *domain-specific knowledge,* information about a specific content area, can influence the individual's ability to remember.

By the time they reach age three or four, many children display organized general knowledge of familiar routines and events, such as birthday parties. Scripts such as these can serve as frameworks within which specific memories are stored.

Knowledge about logical and causal relations among events helps memory, too. When preschoolers witness a logically ordered event such as making "fun dough," they remember more details about the event than when the event consists of arbitrary segments, such as different activities in sand play (Fivush, Kuebli, & Clubb, 1992). Likewise, eleven-month-olds show an excellent ability to imitate the following sequence of causally connected actions: push a button through a slot in a transparent box, then shake it. Imitation will occur even if children are presented with the objects three months after they first saw them; however, arbitrary sequences of actions are not remembered as well (Bauer & Mandler, 1992; Mandler & McDonough, 1995).

The effect of a growing knowledge base on memory has been described in another way: in terms of scripts. **Scripts** are the organized schemes of knowledge individuals possess about commonly encountered events. For example, by the time they are three or four years old, most children have a general schematic representation for the events that occur at dinner time—cooking the food, setting the table, sitting down to eat—as well as for other routine events such as going to school or attending a birthday party (Fivush, 1984; Nelson & Gruendel, 1981). When asked to remember stories based on such familiar scripts, children typically recall script-based activities such as "eating dinner" better than other details less closely related to scripts (McCartney & Nelson, 1981). Thus scripts serve as general frameworks within which specific memories can be stored and may be one of the earliest building blocks for memory.

KEY THEME
Nature/Nurture

Conversations with parents and others probably foster the formation of scripts. When parents reminisce about past events with their children with rich and detailed language, children have better recall about the past (Reese & Fivush, 1993; Reese, Haden, & Fivush, 1993). Thus scripts are likely to be influenced by the types of social experiences the child has. Within this framework, memory is better conceptualized as something children *use* rather than something that they *have* (Fivush, 1997).

script Organized scheme or framework for commonly experienced events.

infantile amnesia Failure to remember events from the first two to three years of one's life.

Autobiographical Memory

Think back to your childhood and try to identify your earliest memory. How old were you? It is unlikely that you will report that you were an infant or perhaps even a toddler. Most people are not able to recount memories for experiences prior to age three years (Pillemer & White, 1989; West & Bauer, 1999), a phenomenon called **infantile**

amnesia. The question of why infantile amnesia occurs has intrigued psychologists for decades, especially in light of the ample evidence that infants and young children can display impressive memory capabilities. Many find that understanding the general nature of **autobiographical memories,** that is, memory for events that have occurred in one's own life, can provide some important clues to this mystery. Between ages three and four, children begin to give fairly lengthy and cohesive descriptions of events in their past (Fivush, Haden, & Adam, 1995). What factors are responsible for this developmental turning point?

KEY THEME
Continuity/Discontinuity

One explanation goes back to some ideas raised by Piaget, namely that children under age two years represent events in a qualitatively different form than older children. According to this line of thought, the verbal abilities that blossom in the two-year-old allow events to be coded in a form radically different from the action-based codes of the infant. The child's emerging verbal skills are, in fact, related to memory for personal experiences. Preverbal children who see unique events at age two do not describe them in verbal terms six months later when they are able to talk. Thus early memories seem to be encoded in a format that cannot be translated into verbal terms later on (Simcock & Hayne, 2002).

KEY THEME
Interaction Among Domains

Another suggestion is that before children can talk about past events in their lives, they need to have a reasonable understanding of the self as a psychological entity (Howe & Courage, 1993, 1997). As we will see in the chapter titled "Self and Values," the development of the self becomes evident between the first and second years of life and shows rapid elaboration in subsequent years. The realization that the physical self has continuity in time, according to this hypothesis, lays the foundation for the emergence of autobiographical memory. One recent study has confirmed that the ability to recognize the self at nineteen months of age predicts the frequency with which children talk about past events when they are a few months older (Harley & Reese, 1999).

According to one view, autobiographical memories arise from children's experiences of talking with their caregivers about past events in their lives. These interactions help children learn a narrative structure for how to talk about the past.

A third possibility is that children will not be able to tell their own "life story" until they understand something about the general form stories take, that is, the structure of narratives (Nelson, 1993a). Knowledge about narratives arises from social interactions, particularly the storytelling children experience from parents and the attempts parents make to talk with children about past events in their lives (Reese et al., 1993). When parents talk with children about "what we did today" or "last week" or "last year," they guide the children's formation of a framework for talking about the past. They also provide children with reminders about the memory and relay the message that memories are valued as part of the cultural experience (Nelson, 1993b). It is interesting to note that Caucasian children have earlier childhood memories than Korean children (Mullen, 1994). American four-year-olds also provide more extensive, detailed descriptions of events in their past than do Korean and Chinese children (Han, Leichtman, & Wang, 1998). By the same token, Caucasian mother-child pairs talk about past events three times more often than do Korean mother-child pairs (Mullen & Yi, 1995). Moreover, Caucasian mothers who ask their children many questions about past events, elaborating on their children's comments or asking for more details (e.g., "And what'd daddy do on the boat?") tend to have children who talk more about the past (Harley & Reese, 1999). Thus the types of social experiences children have factor into the development of autobiographical memories.

A final suggestion is that children must begin to develop a "theory of mind," as described in the chapter titled "Cognition: Piaget and Vygotsky," before they can talk about their own past memories. Once children begin to accurately answer questions such as "What does it mean to *remember*?" and "What does it mean to *know* something?" improvements in memory seem to occur (Perner & Ruffman, 1995).

It may be that the developments just described are intertwined with and influence one another. Talking with parents about the past may enhance the development of the self-concept, for example, as well as help the child understand what it means to "remember" (Welch-Ross, 1995). No doubt the ability to talk about one's past arises from the interplay of several factors, not just one (Pillemer, 1998).

autobiographical memory
Memory for specific events in one's own life.

CONTROVERSY: THINKING IT OVER

How Reliable Is Children's Eyewitness Testimony?

The research on children's memory, particularly recognition memory, suggests that their ability to remember events from the past is very impressive. But as children are increasingly called on to testify in courts after they have witnessed or been victims of abuse, neglect, or other crimes, their capability to render an accurate account of past events has been called into question.

What Is the Controversy?

Just how reliable are children's memories when they are called on to give eyewitness testimony? Children's memories for events, even those that occurred months or years in the past, are remarkably good. On the other hand, children's memories are also susceptible to suggestive or leading questions by attorneys, clinicians, and other interrogators (Bruck & Ceci, 1999; Ceci & Bruck, 1993). The stakes are high regarding these issues. If children have been the victims of crime, the perpetrators should be punished; but if children's memories are inaccurate in these contexts, a criminal suspect might be falsely accused.

What Are the Opposing Arguments?

Some research indicates that children's recall of distinctive events such as a trip to Disney World or a medical emergency is surprisingly complete and accurate even four or five years after the event (Fivush & Schwarzmueller, 1998; Peterson & Whalen, 2001). For example, in one study of two- to thirteen-year-old children who had been treated in a hospital emergency room, even two-year-olds remembered a substantial amount about their injuries when they were interviewed five years later (Peterson & Whalen, 2001). Data such as this suggests that children's memories are reliable.

On the other hand, other studies have shown that children, especially preschoolers, are likely to misreport a past event if they are asked misleading questions. In some of the original studies of "false memories" in children, Stephen Ceci and his colleagues tested children ages three through twelve years on their ability to remember the details of a story (Ceci, Ross, & Toglia, 1987). A day later, children in one of the experimental conditions were asked leading questions that distorted the original information, such as "Do you remember the story about Loren, who had a headache because she ate her cereal too fast?" In the original story, Loren had a stomachache from eating her eggs too fast. Compared with children who did not hear misleading questions, children who heard biased questions made more errors on a subsequent test that required them to select pictures depicting the original story: they chose the pictures showing a girl eating cereal and having a headache. This tendency to err was especially pronounced in children ages four and under.

What Answers Exist? What Questions Remain?

Many factors may influence just how suggestible children are. One is exactly who is doing the questioning. For example, in Ceci's study just described, misinformation provided by an adult tended to distort memory more than misinformation provided by another child; the perceived power of the questioner may make a difference. Second, when children are asked questions repeatedly, particularly *yes-no* questions, they are likely to change their answers or speculate inappropriately (Poole & White, 1991, 1993). Preschoolers especially may perceive the repeated question as a signal that their first answer was incorrect. Repeated questions, even when they are neutral, can lead to false memories because the information contained in them can be incorporated into the "gist" of the real memory (Brainerd & Mojardin, 1998). Third, the use of dolls and props for children to reenact the past event can lead to elevated false reports, especially among younger children (age three) and when this form of interview occurs after a delay of several weeks (Greenhoot et al., 1999). Finally, suggestibility may be reduced when children first are reminded to consider the basis of their information, a phenomenon called *source monitoring* (Poole & Lindsay, 2002; Thierry & Spence, 2002). In one laboratory study, for example, preschoolers were shown a video depicting a story about a boy feeding his dog accompanied by the experimenter's narrative. Some children were first asked to answer "Did you see it on the tape?" or "Did I tell you?" before they were asked leading questions about the story. This group was less likely to be influenced by leading questions compared with a group of children who were asked the leading questions first (Giles, Gopnik, & Heyman, 2002).

An important, and perhaps obvious, consideration in this discussion is that memories—those of both children and adults—generally decline with the passage of time. The results of a recent experiment showed that the amount and accuracy of information children spontaneously recalled about past events went down after two years, especially if they did not have an opportunity to be reminded of the original event. Under the latter conditions, up to 50 percent of the new information children added to their memories after being prompted by an experimenter was found to be inaccurate (Pipe et al., 1999). Because extended periods of time often elapse between a criminal event and the trial, these findings are especially relevant.

Given this information, what is the best way for professionals in the criminal justice system to encourage children to give reliable eyewitness accounts based on what we know from research?

Brain Development and Memory

Ultimately, any account of cognitive development will have to be connected to changes in the structures or processes that occur in the brain. Neuroscientists have been actively exploring brain functioning in both animals and humans to try to establish the underlying substrates of different cognitive processes, including memory. Fruitful approaches have included studying the memory performance of animals that have had different portions of the brain lesioned (or damaged), "scanning" the brain to measure metabolism and blood flow, and recording the electrical activity of the brain while individuals perform memory tasks.

We noted earlier that even very young infants show a robust preference for novel stimuli, indicating their recognition memory for "old" items they have seen before. Infant monkeys show similar patterns of behavior; however, when their hippocampus is removed at fifteen days of age, preferences for novelty disappear (Bachevalier, Brickson, & Hagger, 1993). As Figure 9.9 shows, the hippocampus is a brain structure located below the cerebral cortex that has long been known to be involved in memory functioning. Apparently, the hippocampus, which is a part of the *limbic system,* is an early developing structure that is necessary for the display of fundamental memory processes (Nelson, 1995).

Toward the latter part of the first year, portions of the temporal and prefrontal lobes of the brain (see Figure 9.9) begin to mature, as is revealed by *positron emission tomography,* or PET scans. PET scans allow neuroscientists to measure, among other things, the glucose activity in different portions of the brain. Interestingly, the levels of glucose metabolism in the temporal lobes of monkeys begin to look adultlike at four months of age, the age at which they begin to reach for a novel object after a short delay (Bachevalier, Hagger, & Mishkin, 1991). Similarly, glucose metabolism in the prefrontal lobes begins to appear mature in one-year-old human infants (Chugani, 1994). This is also the age at which infants correctly search for objects in the "A-not-B" task (see the chapter titled "Cognition: Piaget and Vygotsky") and at which they can locate objects after a delay (Nelson, 1995). By the time children reach preadolescence, fMRI data show that their brains respond much as adults' brains do when they engage in a working memory task. Portions of the parietal and prefrontal areas of the cortex, in particular, show unique patterns of activation (Nelson et al., 2000). Thus, as the cortex develops, so does the ability to perform more demanding memory tasks.

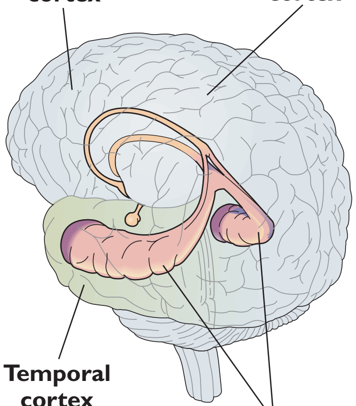


FIGURE 9.9
The Brain and Memory Development

Several regions of the brain are implicated in memory development. The hippocampus matures early, and part of its function may be to direct recognition memory. Portions of the temporal and prefrontal cortex mature later in the first year and apparently are involved in more demanding memory tasks.

Researchers have also begun to record the electrical activity of the brain on-line while infants participate in memory tasks. In one recent study, five-month-old infants heard a succession of one hundred identical stimuli, either a click or a tone. The next day, fifty of the "old" stimuli were presented with fifty "new" ones (e.g., a tone if a click had originally been heard). Electrical firing patterns of the brain were more pronounced for familiar than for unfamiliar stimuli. Brain waves also had less variable onset times for familiar stimuli on the second day compared with the first day (Thomas & Lykins, 1995). Put another way, physiological responses were more consistent and prominent for the stimuli that had been put into memory.

Neuropsychological studies hold great promise in unlocking some of the mysteries of brain-behavior relationships. No doubt, they will also provide important information about the factors that influence cognitive development.

FOR YOUR REVIEW

- What are the major features of recognition memory in infancy?
- How does recognition memory change with age?
- What have different types of recall studies (memory span, elicited imitation, and free recall) told us about age changes in memory performance?
- What factors are primarily responsible for developmental improvements in recall memory?
- What explanations have been offered to account for the emergence of autobiographical memory?
- What major changes in the brain accompany developmental improvements in memory?

The Development of Problem-Solving Skills

One of the most powerful and uniquely human cognitive skills is the ability to solve problems. Whether you are completing an analogy, computing an arithmetic solution, or testing a scientific hypothesis, problem solving typically involves several steps or phases. Often you start with planning the steps to the solution of the problem, considering both the information you have at the start and the final goal. Clearly, you must attend to the portions of the problem that are relevant to its solution. You will probably select from a number of strategies to help you achieve your goal (for example, count on your fingers or use a calculator). In many cases, you must rely on your understanding of what different symbols in the problem (e.g., "+" or "=") represent. Frequently you must draw on a body of information from memory and examine relationships among several pieces of that information. Once you have the solution, you will often apply this new knowledge to similar contexts. Given the number of steps involved and the complex, intertwined relationships among them, you can see why problem solving is considered to be an example of what is called "higher-order thinking."

What are the earliest instances of problem-solving activity in humans? Piaget's descriptions of the development of means-ends behavior during the sensorimotor stage of development, discussed in the chapter titled "Cognition: Piaget and Vygotsky," suggest that infants show the beginnings of problem solving. Other researchers have confirmed that infants are capable of solving problems, combining several subgoals to reach an interesting toy. In an experiment conducted by Peter Willatts (1990), twelve-month-olds saw a barrier in front of a cloth on which was placed a string attached to a toy (Figure 9.10). To get the toy, infants had to remove the barrier, pull the cloth, and then pull the string. In a control condition, the toy was not

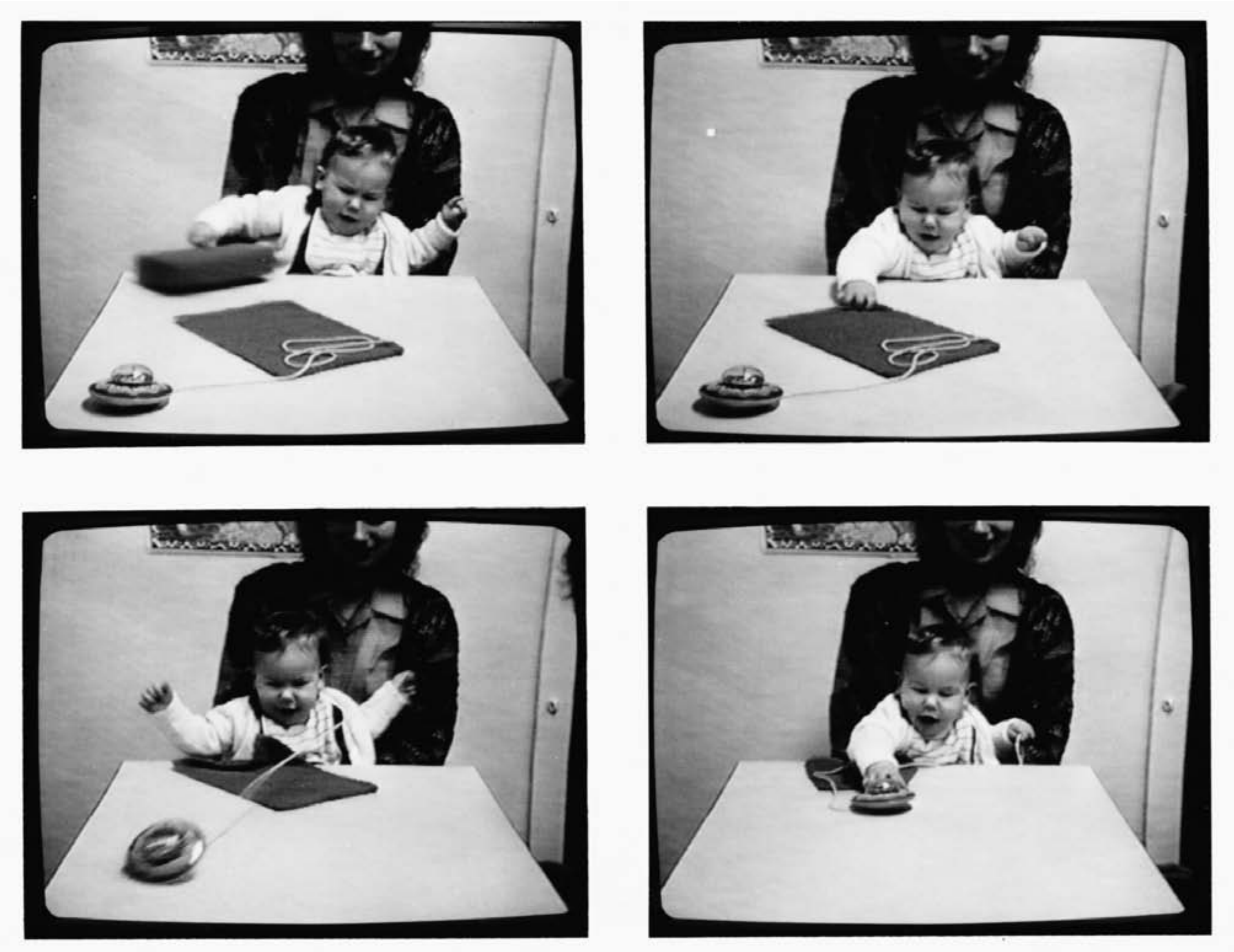


FIGURE 9.10
Simple Problem Solving by Infants

This one-year-old knocks down the barrier and pulls the cloth to obtain the string to which an attractive toy is attached. Such behavior suggests that young infants can deliberately put together several subgoals to reach a goal.

attached to the string. Infants in the first group tended to remove the barrier without playing with it, quickly pulled the cloth, and grasped the string to reach the toy. Their behavior suggested that reaching the attractive toy was of utmost interest. In contrast, infants in the control group played with the barrier, were slower to reach for the cloth, and frequently did not grasp the string, probably because they recognized that the barrier, cloth, and string could not help to bring the toy closer. Willatts (1990) concluded that infants are capable of putting together several subgoals with the deliberate intent of reaching a goal.

KEY THEME
Continuity/Discontinuity

Problem-solving skills become more elaborate and complex as children pass through the preschool and school years. A major question has been whether the child's increasing proficiency in solving complex and abstract problems results from an abrupt, qualitative shift in the ability to think logically or whether improvements in problem solving result from gradual gains in memory, attention, and other component cognitive skills. As we saw in the chapter titled "Cognition: Piaget and Vygotsky," Piaget believed in abrupt, qualitative shifts; he posited that the cognitive structures that permit completely logical and abstract thought do not evolve until adolescence, when children reach the stage of formal operations. In contrast, many information-processing theorists have emphasized the continuous growth and refinement of component skills involved in problem solving. According to them, children of all ages possess the fundamental ability to manipulate information in a logical fashion but may forget some of those elements during the process of problem solution or fail to attend to them sufficiently in the first place. With age, however, improvements in children's attention, memory, or other cognitive skills result in corresponding improvements in problem solving. Let us take a closer look at the components of problem solving that are considered essential in information-processing views of cognitive development.

Components of Problem Solving

Just think about the typical day of the average school-age child and you will undoubtedly discern many problem-solving situations the child encounters: a set of arithmetic problems to complete on a worksheet at school, a computer maze or jigsaw puzzle to solve for fun, or several bus routes to choose from to get to an after-school job. More mature and efficient problem solvers deploy several "executive" cognitive skills, much as the central processor directs the various functions of a computer. For instance, can I add these numbers in my head or should I get a calculator? What is the best strategy to use—should the puzzle be started with the edge pieces or the entire top left corner? Will learning how to do a simple computer maze provide any clues about how to do a more complex one? As researchers have explored children's problem solving, they have discovered a number of developmental changes in important components that characterize higher-order thinking.

● **Representation** One of the most basic capacities required for problem solving is the ability to use symbols—images, words, numbers, pictures, maps, or other configurations that represent real objects in the world. Piaget argued that children are unable to think with symbols, that is, use representations, until near the end of the sensorimotor stage of development at about eighteen months of age. Others, however, have challenged this position and argue that representational capacities are evident much earlier in infancy. Jean Mandler (1988, 1998) has pointed out a number of early abilities infants display that support this thesis. For example, we noted in the chapter titled "Language" that infants begin to use gestures to stand for objects or events prior to age one year. Similarly, young infants' apparent knowledge about the physical properties of objects, described in the chapter titled "Cognition: Piaget and Vygotsky," suggests that they must hold some internal representation of them.

Although infants may have basic representational capacities, toddlers and older children far more readily recognize that external symbols of real objects in the world can be used to further their problem-solving efforts. For example, Judy DeLoache

An important cognitive skill that emerges at about age three is the understanding that a model may *represent* a real-life event. Representation is a fundamental skill necessary for problem solving.

(1987) asked two- and three-year-olds to search for a small toy hidden in a scale model of a room. Next, the children were brought into a life-size room that corresponded to the scale model they had just seen. Could they find the real-life toy that corresponded to the smaller replica in the previous segment of the experiment? If they saw a small Snoopy toy under a miniature couch, would they look for a large Snoopy under the couch in the life-size room? The three-year-olds could find the hidden object on more than 70 percent of the trials. But the two-year-olds could do so on only 20 percent of the trials. Later, when both age groups were asked to locate the toy back in the scale model, they did so with few errors. Thus the search failures of two-year-olds in the life-size room were not due to memory problems. DeLoache believes that two-year-olds have difficulty with *dual representation*, that is, with understanding that a scale model can be both an object in its own right and a representation of a life-size room. By age three, however, children have the cognitive capacity, flexibility, and conceptual knowledge to appreciate that a symbol such as a model can "stand for" a real-life event. In other words, children gain **representational insight** (DeLoache, 2000; DeLoache & Smith, 1999).

Planning One of the hallmarks of a mature problem solver is the ability to plan an approach to obtaining a goal. Planning, of course, depends on representational capacities, because symbols may be employed or manipulated as part of the plan. It also depends on having general knowledge about the events being planned for—what is involved in going grocery shopping versus taking a trip to the beach, for example (Hudson, Shapiro, & Sosa, 1995). Moreover, planning has at least two aspects: (1) deciding on the steps one needs to take ahead of time and (2) knowing when to be flexible and perhaps modify or discard advance plans if the situation calls for it (Baker-Sennett, Matusov, & Rogoff, 1993).

KEY THEME
Child's Active Role

Planning can be observed as young children attempt to solve simple novel problems, such as making a gong out of triangular supports, a metal plate, and a mallet. When two-year-olds in one study were shown the fully assembled gong first, they showed a high proportion of actions that would lead to successful problem solution. Showing the children the goal was much more effective than getting them started with the early steps in solving the problem. Thus information about the end state of the problem was critical in prompting these young children to plan (Bauer et al., 1999).

David Klahr's classic research using the Tower of Hanoi problem, illustrated in Figure 9.11, shows that there are also clear developmental improvements in planning (Klahr, 1978; Klahr & Robinson, 1981). In this problem, one of three pegs has three cans of different sizes stacked on it. The goal is to move the cans to the third peg so they end up in the same order they were on the first peg. Two rules apply: only one can may be moved at a time, and a smaller can cannot be placed on a larger one.

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The Tower of Hanoi

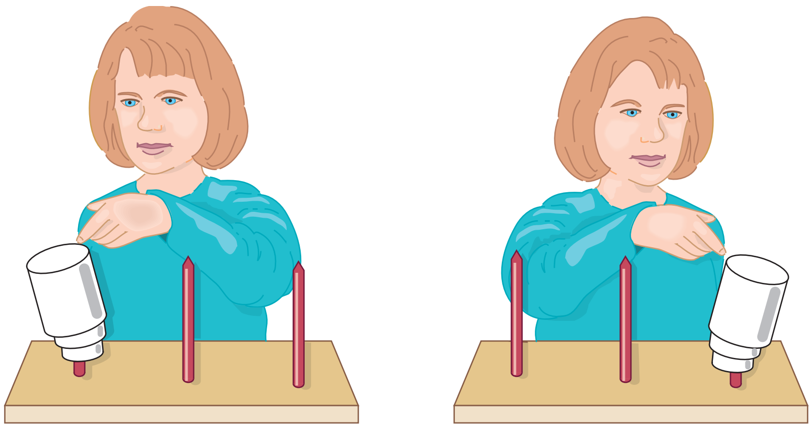
Klahr found that six-year-olds were better planners than three-year-olds in two respects: they were more likely to pursue long-term goals, and they could keep more subgoals in mind as they attempted to solve the problem. For example, three-year-olds single-mindedly moved the cans to the third peg without thinking of the intermediate steps that might be necessary; their plan encompassed only the short-term goal to get the cans to the final peg. They could think of only one or two steps to attain the goal and broke the rules of the game. In contrast, six-year-olds used five or six steps to solve the problem, looking ahead a step or more as they planned their moves and anticipating potential traps in or obstacles to their placement of the cans.

With development, children also show changes in the flexibility of their planning. This phenomenon is illustrated by another study in which children were asked to plan a route through a maze (Gardner & Rogoff, 1990). When the task involved no time pressure, seven- to ten-year-olds planned the entire route through the maze before they drew in the path. However, when the experimenter told children to work as fast as they could, these older children used a more efficient approach under the circumstances: they planned less. Younger children, ages four to seven years, were less likely to adapt their planning strategies to the particular demands of the task.

representational insight The child's ability to understand that a symbol or model can stand for a real-life event.

FIGURE 9.11
The Tower of Hanoi

In the Tower of Hanoi problem, the child must move three cans stacked on the first peg to the third peg so that they end up in the same order. Only one can may be moved at a time, and a smaller can may not be placed on a larger one. This problem gives researchers the opportunity to study developmental changes in children's planning activities as they solve problems.



Initial state **Goal state**

KEY THEME
Nature/Nurture

Planning is likely to develop as children gain experiences with everyday routines in which specific events occur in a temporal order. Parental verbalizations about plans and the child's own emerging ability to verbalize probably also contribute (Benson, 1997). Another ingredient, according to Marshall Haith, is the child's "future orientation," his or her ability to think about events that are yet to come. Although early signs of future orientation are evident in infants—as they show anticipation about events in familiar routines, for example—a sense about the future probably undergoes more complex elaboration as the child matures (Haith, 1997).

KEY THEME
Child's Active Role

● **Strategy Choice** When a child encounters a problem—say, an addition problem—he will most likely choose from among several strategies. Robert Siegler has closely examined children's strategies as they solve simple addition problems and has found that children often rely on more than one approach (Siegler & Crowley, 1991; Siegler & Jenkins, 1989; Siegler & Shrager, 1984). Most children, he noted, first turned to one strategy but also usually had a backup strategy or two. Having multiple strategies affords the child useful flexibility as she encounters new situations and gains new knowledge (Siegler, 1989).

Suppose the child's assignment is to add the numbers 3 and 1. Several strategies are possible. The child can represent each number on his fingers and then count to the total. Alternatively, he can represent the larger number on his fingers and then count off the smaller number. Or he can simply retrieve the information from memory. Siegler found that if the problem was simple, children drew on memory for the answer because that approach is the fastest (Siegler & Shrager, 1984). If the problem was more difficult, however, children used other strategies that ensured greater accuracy, such as counting on their fingers.

WHAT DO YOU THINK?

How Should Math Be Taught?
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With development, as children have more successes with solving problems and become more confident about their approach, they are more likely to use memory as opposed to finger counting to solve addition problems. They also learn new strategies, often when they fail to solve a problem and need to search for alternative solutions. But children can learn from their successes, too. Siegler and Jenkins (1989) noticed that children often came up with new strategies for problems they had solved correctly earlier in the experiment. Children may also discover strategies simply by interacting with the materials for a problem (Thornton, 1999) or by hearing an expert explain a successful strategy (Crowley & Siegler, 1998).

Siegler's research shows that children do not merely substitute one strategy for another as they become more mature problem solvers. Rather, they incorporate new blends of strategies as they learn new ones and discard older ones. Children are constantly selecting from a pool of multiple strategies, depending on whether the task demands that they be fast or accurate and on what they remember about the success of the particular strategy in the past (Siegler, 1989). In their use of strategies, children frequently show variability from one problem-solving session to another, from one child to the next, and from one context to another, such as playing a board game versus doing math (Bjorklund & Rosenblum, 2002; Kuhn et al., 1995; Siegler, 1994). Variability, in fact, may enhance learning because it provides experiences with different problem-solving approaches and opportunities to discover those that work (Siegler, 1996).

KEY THEME
Individual Differences

Examining Research Methods

Using the Microgenetic Approach to Study Children's Problem-Solving Strategies

According to Robert Siegler (Siegler, 1997; Siegler & Crowley, 1991), cross-sectional and longitudinal studies of cognitive development may not reveal a complete picture of cognitive development. When researchers use these methods, they tend to focus on average differences in performance from one time to the next or from one age group to another. But this approach usually does not tell us much about the precise cognitive processes that change as the child develops. A key feature of the **microgenetic approach** is examining a child's performance *while* she is engaged in a cognitive task, making note of any changes in behaviors that occur from trial to trial. Through this close analysis of the child's progress from one level of understanding to another, we can glean important details about development and have a better appreciation for the mechanisms that are responsible for change.

An experiment conducted by Robert Siegler and Elsbeth Stern (1998) illustrates this method. These researchers were interested in second-graders' tactics as they solved arithmetic problems that involved the principle of inversion—for example, 35 + 8 – 8. Here, it is possible to use a shortcut to arrive at the answer—the quantity (8 – 8) can be quickly discounted because the result is 0. Only children who did not know the inversion principle were selected to participate. In solving these problems, what kinds of strategies would children use? With repeated practice with these problems, would they eventually learn the inversion principle? Several strategies for solving the inversion problems were defined by the researchers:

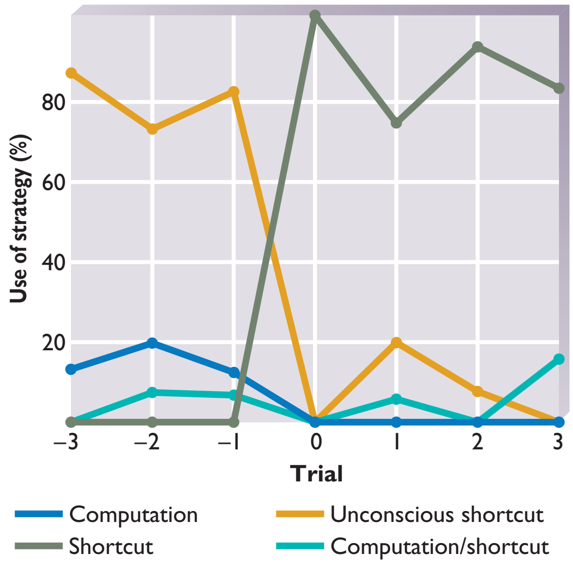
- *computation*: adding all of the numbers
- *negation*: adding the first two numbers but then answering without subtracting the third number
- *unconscious shortcut*: a quick answer, with a vague reference to computation or negation in the child's explanation but no evidence of actually computing the second and third numbers (i.e., the child uses the inversion principle but cannot explain it)
- *computation shortcut*: actual computation but then an explanation that the shortcut would work (i.e., the child does not use the inversion principle but can explain it)
- *shortcut*: a quick answer, no evidence of computation, and an explanation of the inversion principle.

The strategies in this list were presumed to increase in sophistication from top to bottom. In the experiment, one group of children received twenty inversion problems, and a second group received ten inversion problems and ten standard problems (e.g., 35 + 8 – 2) over a total of six practice sessions. After each individual problem was completed, the researcher asked the child how he or she figured out the problem. The researchers noted the child's numerical answer, the time it took to solve the problem, the explanation the child provided, and any other behaviors that occurred during the trial. Figure 9.12 shows a portion of the results for children who received blocks of twenty inversion problems.

microgenetic approach A research approach in which detailed trial-to-trial observations are made of individual children's performances.

FIGURE 9.12
A Microgenetic Analysis of Children's Strategy Use

In Siegler and Stern's (1998) experiment, children were closely observed as they solved a series of problems involving the inversion principle. The best strategy to use was a shortcut (e.g., 8 – 8 = 0). Trial 0 on this graph represents the point at which each child began to use this strategy. Notice that on previous trials (e.g., Trial –3), many children were using an unconscious shortcut, as opposed to computation, to solve the problems. (Note that in this particular portion of the study none of the children used negation.) A microgenetic approach allows researchers to understand more of the details of the *process* of development.



Source: Siegler & Stern, 1998.

In the graph, Trial 0 represents each child's first use of the best strategy, the shortcut (thus 100 percent of the children are represented at this point). Notice that three trials before Trial 0, on Trial –3, 87 percent of the children were using the unconscious shortcut, but very few were using computation or any other strategy. This pattern suggests that right before children discover the actual shortcut, they use it without being fully aware of it or being able to verbalize it. This pattern of results, by the way, did not emerge for children who had mixed sets of inversion and standard problems. Instead, they relied more on computation shortcuts right before they discovered the inversion principle.

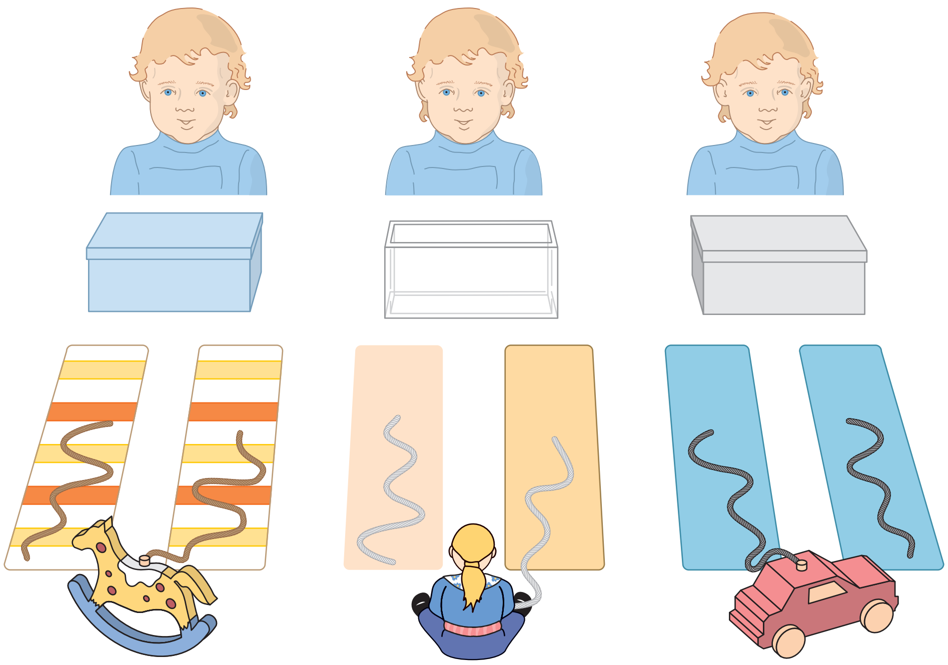
As you can see, fine-grained analyses of trial-to-trial changes in children's responses can provide rich information about the way their thought processes change. Can you think of other ways that the microgenetic approach can be used to study various aspects of cognitive development? Are there any disadvantages to using this approach?

● **Transferring Skills** One final essential element in higher-order thinking is the ability to use what you have learned in one situation and apply it to other, similar problems. How well do children extend their existing problem-solving skills to new circumstances? This has been a long-standing question in psychology, particularly among researchers who have studied the role of generalization in learning. It has also been a question of paramount importance to educators, who assume children will find some application in their everyday lives for what they have learned in the classroom.

The ability to transfer knowledge requires that children learn the original problem well, note the resemblance between the old and new problems, and apply the appropriate activities to the new problem. This process is called **analogical transfer** in that the child must notice the one-to-one correspondence that exists between the elements of one problem and those of another and then apply the familiar skills to the novel context.

An experiment by Ann Brown and her coresearchers illustrates how this process can occur (Brown, Kane, & Echols, 1986). Three- to five-year-olds were read a story in which a magical genie had to move his jewels from one bottle across a high wall to another bottle. Several items were available to help the genie: glue, paper clips, sheets of paper, and so on. The experimenter and each child enacted the solution, rolling up the paper into a tube and using it to transport the jewels from one bottle to the other. The children were then presented with a different problem having the same general solution (a rabbit that needs to get its Easter eggs across a river can roll paper

analogical transfer Ability to employ the solution to one problem in other, similar problems.



Source: Chen, Sanchez, & Campbell, 1997.

FIGURE 9.13
Transfer of Problem Solutions Among Infants

Even one-year-olds can transfer the solution of one problem to another when the goal sequences are similar. Each of these problems requires the child to bypass a barrier, pull the cloth, and grab the string to obtain the toy. Infants who were successful in solving one of these problems could typically solve the others, even though the problems were not perceptually identical.

into a tube to transport them). Whether the children were able to transfer the solution to a new problem depended on whether they recalled the goal structure of the previous problem. If they remembered the major actor, his goal, and the solution to his problem, even three-year-olds could solve the new problem. In fact, based on children's performance on a variety of problem-solving tasks employed by Ann Brown and other researchers (Baillargeon & DeVos, 1991; Brown, 1990), Usha Goswami (1996) has concluded that certainly toddlers, and possibly even infants, demonstrate analogical transfer.

Brown hypothesized that for transfer of problem solving to take place, the child must represent the problem in general mental terms, that is, abstract out the goal, problem, and solution dissociated from the specific fact that it was a genie who had to transfer jewels. Children can be encouraged to discern such common goal structures in consecutive problems. Zhe Chen and Marvin Daehler (1989) found that when six-year-olds were explicitly prompted to formulate an answer to the question of how problems were alike, they then performed significantly better on a transfer problem than control participants who did not receive this training. Thus parents and teachers may play a crucial role in facilitating the transfer of learning by pointing out commonalities across several problems. In fact, there are some circumstances in which very young children can discern the similarities across problems themselves. For example, when problem-solving situations look perceptually different but share similar goal sequences (e.g., remove a barrier, pull the correct cloth, and pull the correct string to reach a toy, as shown in Figure 9.13), even infants who are one year of age show the ability to transfer the solution to other problems once they have been successful with the first (Chen, Sanchez, & Campbell, 1997).

KEY THEME
Nature/Nurture

Research Applied to Education

Facilitating Transfer in the Classroom

As the teacher collected each student's paper, Nate was thinking how glad he was to have the geography test over with. Science was next, and science was without doubt his favorite subject in school. The class was studying electricity and had learned about how to make a circuit, the properties of conductors and insulators, and the role of

One technique that teachers can use to facilitate transfer of knowledge from one situation to another is to present information using an obvious organizational structure. Explaining to students why the material they are learning is important can also be helpful.

a battery. Now the teacher was asking pairs of students to make a series of three light bulbs work by putting together wires and batteries in the correct order. Nate and his partner, Eliza, looked at the equipment before them and were stumped. How would they even begin? As they experimented, though, the principles they discussed in the previous day's lesson began to creep into their thinking. By the end of only a few minutes, their bulbs were assembled and shining as brightly as their proud faces.

If you stop and think about it, probably the greatest overarching goal of education is to ensure that students transfer what they learn in one lesson, problem, or assignment to new situations both in and outside of the classroom. We expect students to go beyond the specific content of one particular mathematics problem, scientific experiment, or writing assignment and apply what they have learned in new situations. Is there anything teachers can do to promote this important process?

Robert Sternberg and Peter Frensch (1993) offer the following suggestions based on their review of numerous studies of both memory and transfer:

1. *"Teach for transfer" by providing multiple settings in which information is encoded.* This tactic, according to numerous studies of memory, should make retrieval of information more likely because there are more cues associated with it. Teachers should demonstrate to students how information they learn can be applied in different contexts and even ask students to think of applications themselves. That is, knowledge should not be "encapsulated" or taught as a "stand-alone" topic. As an example, principles of algebra could be taught in the context of a science class as well as a math class. The results should be that those principles are remembered well and their usefulness in different subject areas is apparent to students.

2. *Organize information so that transfer is more likely to occur.* Classroom presentations should have an obvious organizational structure and should be connected to information students already have. Such an approach would provide students with

a framework, much like a *script,* that would enhance understanding and learning. Sternberg and Frensch (1993) add that teachers rarely begin lessons with a discussion of why the information is important in students' lives (i.e., where it fits in their personal scheme of things), but to enhance learning, they should.

3. *Help students see the general features that are common across different content areas to be learned and that are specific to a given lesson.* Sternberg and Frensch (1993) describe a personal experience in learning Spanish in which the general features of the language were explicitly pointed out. At the same time, pronunciations and vocabulary that were unique to a given region or country were also highlighted for students. Learning should proceed more efficiently under circumstances in which common themes and exceptions to those themes are deliberately highlighted.

4. *Test students on their ability to apply what they have learned to new situations rather than on their ability to recall specific pieces of information.* This approach would establish in students a "mental set" for the idea that they will have to engage in transfer—that this is an important expectation of them.

All of these pointers have a common aim: to make students aware of transfer as an explicit goal of learning. In a sense, the preceding suggestions ask teachers and students to be more "metacognitive" about the learning process, to overtly and frequently discuss and reflect on how transfer might be promoted. The more teachers incorporate this goal into their daily classroom instruction, according to these researchers, the more likely students will learn in the truest sense of the word.

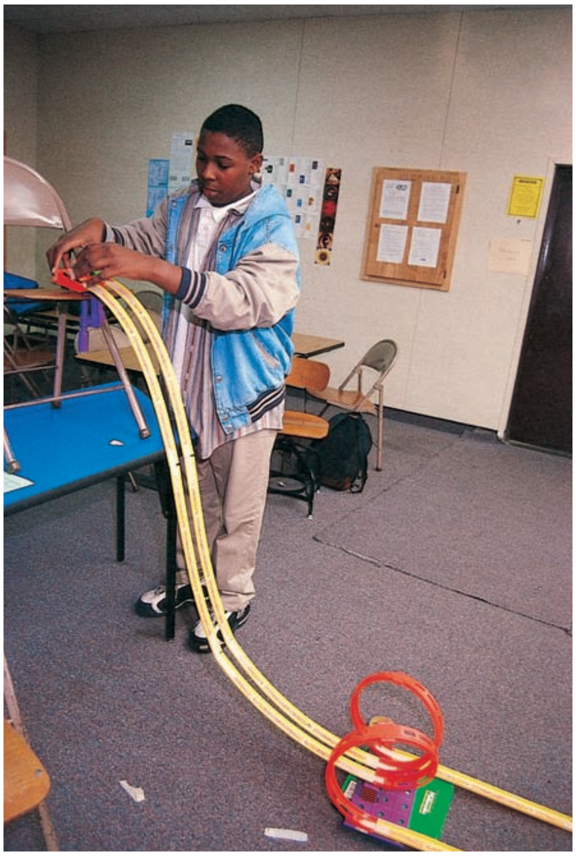
The Development of Scientific Thinking

Most of us have received at least some formal training in the complex type of reasoning called *scientific thinking*. Scientific reasoning involves formulating a hypothesis, designing experiments in which one factor varies while others are held constant, and deciding on the validity of the hypothesis based on the observable evidence. According to Piaget, you will recall, this form of logical thought is not observed prior to the start of the formal operational stage, usually at preadolescence. Contemporary research confirms that there are indeed observable developmental accomplishments in scientific reasoning; however, children who are just starting school show impressive knowledge about some of the basic tenets of scientific thinking.

One element of scientific thinking is the ability to distinguish between theory and evidence. Preschoolers often behave as if there is no distinction between the two. Shown a series of pictures depicting two runners in a race, younger children typically answer the questions, "Who won?" and "How do you know?" with theory (e.g., "He has fast sneakers") rather than evidence (e.g., "He's holding the trophy"). By age six, though, children are likely to cite objective evidence (Kuhn & Pearsall, 2000).

A related skill is the capacity to see which conclusions are warranted by the evidence. Let us consider one example in which the child is presented with a series of pictures depicting the phases of the moon along with two theories about why they occur: (1) clouds cover different portions of the moon at different times, or (2) the moon has a dark and a light side. Then the child hears the evidence: an astronaut reports that the moon is dry and has no water, that he landed on some white rock, and that he later walked on black gravel. Which theory about the moon could possibly be correct? Most first-, third-, and fifth-graders in this study chose the second theory, the one that was consistent with the evidence (Samarapungavan, 1992). Other researchers have confirmed that first-graders can correctly identify whether a specific piece of empirical evidence provides conclusive or inconclusive support for a hypothesis (Sodian, Zaitchik, & Carey, 1991).

Yet scientific thinking involves greater complexities. For example, hypotheses must be formed in the first place, and usually several hypotheses are concurrently in the mind of the scientist. Often several variables operate at the same time. Experiments



Research shows that when children have the opportunity to engage in repeated scientific problem solving, they become more proficient in designing experiments and drawing valid conclusions from them. For example, several variables can potentially determine the speed of a moving car. With experience, children become better able to propose experiments in which only one variable changes while the others are held constant so that the cause of greater speed can be determined.

must be designed and conducted and their outcomes coordinated with the hypotheses to determine which variable causes the observed outcomes (Klahr & Dunbar, 1988). It is here that developmental changes are most apparent. When third-graders are asked to generate and evaluate hypotheses by running a series of experiments, they usually are not systematic in designing experiments that isolate the key variable and do not write down the outcomes of their experiments. Sixth-graders show improvements but still design a limited number of experiments, and their experiments are often difficult to interpret. Adults do the best, but not because their reasoning about the relationship between theory and evidence is stronger. Rather, adults can coordinate the generation of hypotheses with the design of the set of experiments necessary to test them (Klahr, Fay, & Dunbar, 1993).

KEY THEME
Nature/Nurture

When children are encouraged to engage repeatedly in scientific problem solving, their skills improve noticeably. Deanna Kuhn and her colleagues (Kuhn, Schauble, & Garcia-Mila, 1992) asked preadolescents to identify which variables affected the speed of a model boat being towed in a tank of water: the water depth, boat size, boat weight, sail color, or sail size. The instructor gave minimal feedback to the students, but they were encouraged to make a plan about what they wished to find out, state what they found out after each experiment, and record their findings in a notebook. The results showed that over only a few weeks of repeated exposure to these problems, students became markedly more proficient at designing valid and focused experiments and at drawing valid inferences from the data they collected. Follow-up studies show that this knowledge is subsequently applied to new problems (Kuhn et al., 1995; Schauble, 1996).

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Science Education on TV

Direct instruction helps children master principles of scientific reasoning, too. In a recent study, seven- to ten-year-olds received explicit training on the concept "controlling variables in an experiment." They were provided with examples of confounded and unconfounded experiments and were then asked to apply their knowledge to a sample experiment. Children who had received this training were able to apply the principle of "controlling variables" to several different experiments and were more likely to do so than children who had not received instruction. Thus the ability to reason like a scientist is clearly within the grasp of elementary school students (Chen & Klahr, 1999; Klahr, Chen, & Toth, 2001).

A good way to capture the development of scientific thinking is provided by Deanna Kuhn and her colleagues, who say that children acquire increasing control over their own thought processes. By becoming aware of the differences between theory and evidence, fact and opinion, and by coordinating theories with evidence, children begin to be able to "know how they know" (Kuhn & Pearsall, 2000). In that sense, the steps in the development of scientific reasoning may reflect broader accomplishments in the cognitive domain, as we discuss here.

The Executive Function

KEY THEME
Child's Active Role

Numerous times in this chapter, we have mentioned that with development, children are better able to control their cognitive processing—their attention and memory, for example. As children develop, they become better able to analyze the tasks they face, size up their own capabilities, deploy and modify strategies, inhibit certain behaviors if they have to, and monitor the effectiveness of their approaches. The control of cognitive processing is also very important in problem solving, which, as we saw in this chapter, can involve complex tasks such as planning and transfer. Researchers have recently begun to turn their attention to understanding the role and development of this **executive function** that is part of the information-processing model with which we began this chapter. A key aspect of the executive function is *coordination* of components of cognitive processing in order to achieve some goal (Welsh, 2002).

KEY THEME
Interaction Among Domains

Neuropsychological studies of children who have experienced brain damage indicate that executive function skills seem to stand apart from other cognitive abilities; affected children may show normal language and sensory abilities but have difficulties with planning and inhibition (Espy & Kaufmann, 2002). The prefrontal cortex of the brain has been implicated as one area responsible for the executive function, although there may be others. Thus, as the cortex of the brain matures, we would expect children to show gains in their executive function capabilities.

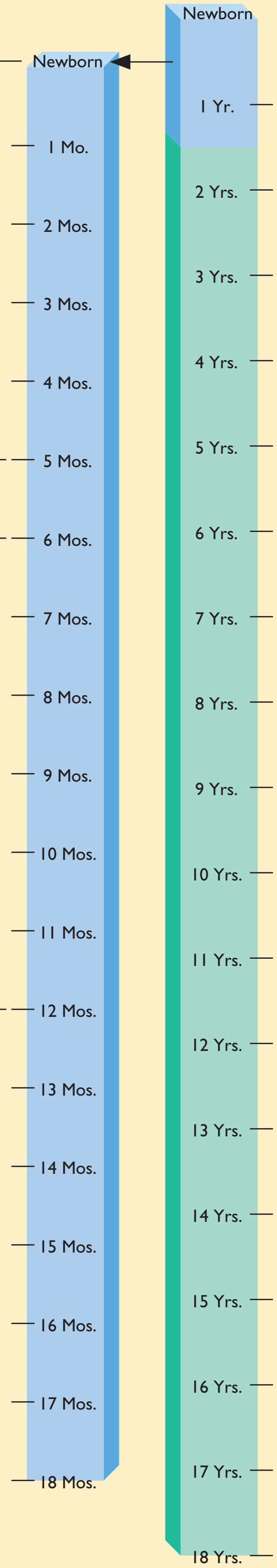
On the behavioral level, one manifestation of the child's executive function skills is the growth of **metacognition**, the child's awareness and knowledge of cognitive processes. The beginnings of this process are evident in the preschooler's emerging *theory of mind*, discussed in the chapter titled "Cognition: Piaget and Vygotsky." Children become aware of the difference between *thinking* about something and *seeing* it, and they understand the meanings of other psychological states such as *belief* and *desire*. Preschoolers, though, often perform cognitive tasks without being fully reflective about their actions. For example, in one experiment, three-year-olds readily sorted objects on the basis of either color or shape, but they could not switch from one rule to the other. When questioned, they could state the second rule for sorting given to them by the experimenter, but they could not link it to their actions (Zelazo & Frye, 1998).

Metacognitive awareness grows through the school years, as does the ability to act on that awareness, as you saw in our discussions of attention and memory. However, adolescents (or even adults) do not necessarily reach the most mature levels of metacognition (Kuhn, 2000a, 2000b). For example, adolescents and adults engaged in decision making are often influenced by their current belief systems. They are vulnerable to judgment biases, and operate according to their personal beliefs about social groups or how things look. Most adolescents are vulnerable to the gambler's fallacy, for example, saying that if a person has just won 75 percent of the time in video poker, she is destined to lose on the next turn (Klaczynski, 2001). They are also influenced by biases toward their own group, such as the religion to which they belong (Klaczynski, 2000).

executive function Portion of the information-processing system that coordinates various component processes in order to achieve some goal.

metacognition Awareness and knowledge of cognitive processes.

CHRONOLOGY: *Cognitive Development II*



Newborn

- Shows recognition memory for simple stimuli.

5–6 Months

- Shows more deliberate shifts of attention.

1 Year

- Shows long-term recall in elicited imitation tasks.
- Performs simple problem solving by combining subgoals.
- Can transfer solutions across problems with similar goal sequences.

2 Years

- Has memory span of about two items.
- Uses naming and looking as simple memory strategies.
- Shows elementary planning capabilities.

3 Years

- Shows recognition memory for fifty-plus items.
- Has memory span of about three items.
- Knows scripts for familiar routines.
- Displays autobiographical memory.
- Shows representational insight.
- Shows analogical transfer following training and the ability to map relations between sets of stimuli.

4–6 Years

- Uses systematic and efficient attention strategies.
- Has memory span of about four to five items.
- Can think of several steps in planning solutions to problems.
- Can distinguish between theory and evidence.

7–8 Years

- Produces rehearsal as a memory strategy.
- Has memory span of about five to six items.
- Shows flexibility in planning solutions to problems.
- Shows growth in metacognition.

9–10 Years

- Shows improvement in focused and selective attention.
- Produces organizational and retrieval strategies for memory.
- Develops scientific reasoning skills.

11 Years

- Produces elaboration strategies for memory.

This chart describes the sequence of cognitive development based on the findings of research. Children often show individual differences in the exact ages at which they display the various developmental achievements outlined here.

The Cognitive Development II chronology chart summarizes the major developmental changes that occur in the information-processing system. Keeping this concept of executive function in mind, you will find many examples in which children are better able to control and coordinate their thinking as they develop. Because of its influence on learning in school, as well as on the ability to regulate the self (see the chapter titled "Self and Values"), research on executive function is likely to grow in the next several years. In fact, according to some researchers, it may be the most important cognitive skill of all (Kuhn, 2000a).

FOR YOUR REVIEW

- When do children first evidence the ability to engage in problem solving? What types of studies have demonstrated this skill?
- What kinds of changes have researchers observed in young children's ability to demonstrate representational insight?
- What are the major ways in which children show changes in planning skills as they develop?
- How have the results of microgenetic studies of problem solving challenged more traditional beliefs about children's strategy use?
- What factors encourage children to engage in the transfer of skills from one situation to another?
- What basic scientific reasoning skills do children who are just starting school display? What kinds of changes occur in these skills with development?
- What role does the executive function play in cognitive processing? In what ways does the executive function change with development?

CHAPTER RECAP

Summary of Developmental Themes

■ **Nature/Nurture** ***What roles do nature and nurture play in cognitive development?***

Some of the changes in cognition documented by information-processing theorists have links to underlying alterations in the structure of the brain. For example, changes in attention and, perhaps, the speed of information processing may be associated with maturation of parts of the central nervous system. Likewise, changes in memory have been observed to accompany the maturation of certain portions of the brain. These connections between cognition and biology point to the role of nature. On the other hand, the child's exposure to specific experiences that nurture the emergence of cognitive skills is also important. As an example, parents and teachers serve as important guides for how to approach cognitive tasks such as planning and transfer of learning.

■ **Sociocultural Influence** ***How does the sociocultural context influence cognitive development?***

The culture in which the child grows up plays a vital role in cognitive development. Cognitive skills such as memory strategies or the notion of autobiographical memory may be transmitted directly by parents, teachers, or other experts in the environment. They may also be transmitted more indirectly through the types of problems and tasks children confront.

■ **Child's Active Role** ***How does the child play an active role in the process of cognitive development?***

Many of the child's cognitive achievements reflect active rather than passive processing. From the child's increasing control of his or her attention to the deployment of memory strategies, from the use of planning in problem solving to the selection of strategies in problems, the portrait of the child that emerges from studies of cognition is of an engaged, dynamic processor of information.

■ **Continuous/Discontinuity** ***Is cognitive development continuous or discontinuous?***

Most information-processing researchers reject the notion that there are qualitative, stagelike changes in cognition with development. Their studies have confirmed that successive increments occur in cognitive skills such as attention and memory.

■ **Individual Differences** ***How prominent are individual differences in cognitive development?***

Information-processing theorists have focused on documenting general changes in cognition with age and, until recently, have been relatively unconcerned with individual differences. Nonetheless, the general features of information-processing skill may vary from child to child. A case in point is ADHD, which appears to involve significant disruptions in attention skills. Individual differences may also be observed in the extent and effectiveness with which strategies are implemented in memory and problem solving.

■ **Interaction Among Domains** ***How does cognitive development interact with development in other domains?***

There are many examples of how cognition is influenced by development in other domains. For example, cognition may be affected by maturation of the central nervous system, which is hypothesized to contribute to the development of sustained attention; the speed of information processing; and memory. Social interactions with parents, teachers, and others form the basis for cognitive development within a given cultural context. At the same time, cognitive development affects how the child functions in other arenas, such as language, emotion, and social interactions.

Summary of Topics

The Information-Processing Approach

- Information-processing theories emphasize the flow of information through the cognitive system.
- *Multistore models* include such structures as the *sensory register*, *working memory*, and *long-term memory*, as well as control processes such as rehearsal.
- *Limited-resource models* describe tradeoffs between energy used to operate on stimuli and the capacity left over for storage.

The Development of Attention

Sustaining Attention

- An important developmental change occurs in the ability to keep one's attention on some stimulus or activity. This change is due, in part, to maturation of the central nervous system, as well as the growing complexity of the child's interests.

Deploying Attention

- With development, children gain in the ability to control their attention in a systematic and efficient manner.

Selective Attention

- As children grow older, they are better able to select certain aspects of the environment to attend to. Physiological maturation and the child's increasing control over cognitive processing are responsible for these changes.
- ADHD is a developmental disorder linked to problems of attention. Problems with executive control and allocating resources in working memory are thought to underlie this disorder.

The Development of Memory

- Researchers distinguish between *episodic memory* (memory for events that took place at a specific time and place) and *semantic memory* (memory for general concepts or facts). They also distinguish between *recognition memory* (knowing that a stimulus has already been encountered) and *recall memory* (the ability to reproduce previously encountered stimuli).

Recognition Memory

- Habituation and operant-conditioning studies show that young infants have very good recognition memory. Stimuli seen for only brief periods can be remembered for days or weeks.
- Early memories are easily disrupted by changes in context, but they can be enhanced by reminders that occur shortly after the original event.
- Even newborns display the capacity for recognition memory. Older children show impressive levels of recognition performance.
- Developmental changes in recognition include an increase in the number of items that can be remembered, as well as an increase in the speed of remembering.

Recall

- From preschool to preadolescence, children show an increase in *memory span*, the number of items that can be recalled after a brief period of time. Changes in *processing speed*, the rapidity with which cognitive activities can be carried out, contribute to this increase.
- *Elicited imitation* studies, in which preverbal children must reconstruct a unique past event from an array of stimuli, show that long-term recall is possible in this age group.
- Children participating in free-recall tasks typically show *primacy* and *recency effects*. The former refers to elevated recall at the beginning of the list and reflects rehearsal. The latter refers to good recall for the last few items in a list.
- As children progress through the school years, they show an increase in the deliberate production of memory strategies for both encoding and retrieval. Among these are *rehearsal* (repeating items), *organization* (reordering items on the basis of higher-order relationships), and *elaboration* (linking items in an image or sentence). Younger children's failure to generate these strategies is called *production deficiency*.

- At the early stages of strategy use, children may show *utilization deficiencies*, the failure of the strategy to enhance recall.
- Improvements in memory are tied to the child's increasing control over his or her cognitive processing. One aspect of cognitive control is *metamemory*, the child's understanding of memory as a process. Improvements in cognitive inhibition and reliance on the gist of an event are also part of this process.
- Children's memory is particularly impressive in domains in which they have extensive general knowledge. The formation of *scripts*, organized schemes for commonly experienced events, also contributes to improvements in memory.

Autobiographical Memory

- Few people can remember events that occurred prior to age three, a phenomenon called *infantile amnesia*. Improvements in memory for specific events in one's life, or *autobiographical memory*, are tied to the child's emerging verbal skills, growing awareness of the self, and increasing understanding of the form of a narrative.

Brain Development and Memory

- Neuropsychological studies indicate that memory development is tied to maturation of several brain structures, including the hippocampus and temporal, prefrontal, and parietal lobes of the cortex.
- Patterns of electrical activity in the brain change during the process of remembering.

The Development of Problem-Solving Skills

- Infants about one year of age show the ability to solve problems in that they will put together several steps to achieve a goal.

Components of Problem Solving

- By age three, children attain *representational insight*, the ability to use a symbol for a real-world event.
- With development, children are better able to plan the steps in problem solving. They also become more flexible in their strategy use.
- Research using the *microgenetic approach* has found that children usually select from a pool of problem-solving strategies rather than simply switch from one strategy to another.
- With development, children improve in their ability to employ one problem solution to other, similar problems, a process called *analogical transfer*. Several factors can influence the likelihood of transfer, such as making the parallels between problems more obvious to children.

The Development of Scientific Thinking

- One important element of scientific thinking is the ability to distinguish between theory and evidence, a capability that emerges around age six. At this age, children are also able to identify which evidence supports a given hypothesis.
- Developmental changes are most apparent in the ability to design systematic experiments to test hypotheses. This ability can be enhanced, though, with increased experiences in scientific problem solving, as well as direct instruction on how to design an experiment without confounds.

The Executive Function

- Researchers are beginning to recognize that an important element in cognitive development is the ability to control and coordinate one's own cognitive processes, a concept called the *executive function*.
- One element of the executive function is *metacognition*, the child's awareness and knowledge of cognitive processes. Metacognitive awareness grows through the school years and adolescence but may not reach full maturity. Even adults' decisions can be influenced by judgment biases.