Here are some questions we will explore in this chapter:

1. What are the key issues in measuring intelligence? How do different researchers and theorists approach the issues?
2. What are some information-processing approaches to intelligence?
3. What are some alternative views of intelligence?
4. How have researchers attempted to simulate intelligence using machines such as computers?
5. Can intelligence be improved, and if so, how?
6. How does intelligence develop in adults?

BELIEVE IT OR NOT — Can Our Expectations Really Affect Our Cognitive Performance?

Intelligence can be improved by training people to remember, represent information, and reason. One factor, however, greatly affects intelligence and performance: the belief that intelligence is changeable. Math students who believed in the malleability of intelligence showed an increase in math achievement over two years, whereas those who did not believe in the malleability of intelligence did not experience a significant increase in achievement. Additionally, math students with declining grades who were taught that intelligence is changeable were able to stop the decline of their grades compared with their peers (Blackwell, Trzesniewski, & Dweck, 2007). In other words, not only intelligence itself, but also beliefs about intelligence affect how intelligence shows itself in academic performance.

Human intelligence can be viewed as an integrating, or "umbrella," psychological construct for a great deal of theory and research in cognitive psychology. Intelligence is the capacity to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the surrounding environment. It may require different adaptations within different social and cultural contexts. People who are more intelligent tend to be superior in processes such as divided and selective attention, working memory, reasoning, problem solving, decision making, and concept formation. So when we come to understand the mental processes involved in each of these cognitive functions, we also better understand the bases of individual differences in human intelligence.

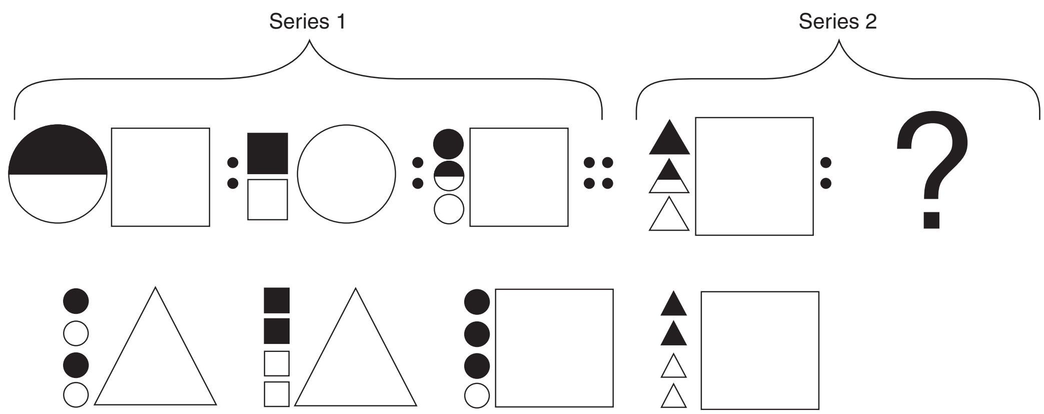
Each of the tasks in the *Investigating Cognitive Psychology* feature is believed, at least by some cognitive psychologists, to require some degree of intelligence. Intelligence is a concept that can be viewed as tying together all of cognitive psychology. Just what is intelligence? In a recent article, researchers identified approximately 70 different definitions of intelligence (Legg & Hutter, 2007). In 1921, when the editors of the *Journal of Educational Psychology* asked 14 famous psychologists that question, the responses varied but generally embraced these two themes. First, intelligence involves the capacity to learn from experience. Second, it involves the ability to adapt to the surrounding environment. Sixty-five years later, 24 cognitive psychologists with expertise in intelligence research were asked the same question (Sternberg & Detterman, 1986). They, too, underscored the importance of learning from experience and adapting to the environment. They also broadened the definition to emphasize the importance of

INVESTIGATING COGNITIVE PSYCHOLOGY

Intelligence

Before you read about how cognitive psychologists view intelligence, try responding to a few tasks that require you to use your own intelligence:

1. Candle is to tallow as tire is to (a) automobile, (b) round, (c) rubber, (d) hollow.
2. Complete this series: 100%, 0.75, 1⁄2; (a) whole, (b) one eighth, (c) one fourth.
3. The first three items form one series. Complete the analogous second series that starts with the fourth item:



Answer options: (a) (b) (c) (d)

4. You are at a party of truth-tellers and liars. The truth-tellers always tell the truth, and the liars always lie. You meet someone new. He tells you that he just heard a conversation in which a girl said she was a liar. Is the person you met a liar or a truth-teller?

Source: Sternberg, *Cognitive Psychology* 5e, page 529.

metacognition—people's understanding and control of their own thinking processes. Contemporary experts also more heavily emphasized the role of culture. They pointed out that what is considered intelligent in one culture may be considered less intelligent in another culture (Ang, Van Dyne, & Tan, 2011; Serpell, 2000). **Intelligence** is the capacity to learn from experience, using metacognitive processes to enhance learning, and the ability to adapt to the surrounding environment. It may require different adaptations within different social and cultural contexts (Niu & Brass, 2011; Saklofske et al., 2015; Sternberg, 2004).

Most of us have our own implicit (unstated) ideas about what it means to be smart. That is, we have our own *implicit theories* (usually unstated conceptions) of intelligence. We use our implicit theories in many social situations. For example, we use them when we meet people and evaluate their intelligence. We also use them when we describe people we know as being very smart or not so smart (Grigorenko et al., 2001; Sternberg, 1985b).

Within our implicit theories of intelligence, we also recognize that intelligence has somewhat different meanings in different contexts. A smart salesperson may show a different kind of intelligence than a smart neurosurgeon or a smart accountant. Each of them may show a different kind of intelligence than a smart choreographer, composer, athlete, or sculptor. Often, we use our implicit and context-relevant definitions of intelligence to make assessments of intelligence. Is your mechanic smart enough to find and fix the problem in your car? Is your physician smart enough to find and treat your health problem? Is this attractive person smart enough to hold your interest in a conversation?

Implicit theories of intelligence may differ from one culture to another. For example, there is evidence that Chinese people in Taiwan include interpersonal and intrapersonal (self-understanding) skills as part of their conception of intelligence (Yang & Sternberg, 1997). Rural Kenyan conceptions of intelligence encompass moral as well as cognitive skills (Grigorenko et al., 2001). Thus, what might count as a comprehensive assessment of intelligence could differ from one culture to another (Sternberg & Kaufman, 1998). Even within the United States, many people have started viewing the emotional aspects of intelligence as important as the cognitive aspects of intelligence. **Emotional intelligence** is "the ability to perceive and express emotion, assimilate emotion in thought, understand and reason with emotion, and regulate emotion in the self and others" (Mayer, Salovey, & Caruso, 2000, p. 396). There is good evidence for the existence of some kind of emotional intelligence (Cherniss et al., 2006; Ciarrochi, Forgas, & Mayer, 2001; Mayer, 2014; Mayer & Salovey, 1997; Salovey & Sluyter, 1997), although the evidence is mixed (Davies, Stankov, & Roberts, 1998; Waterhouse, 2006). The concept of emotional intelligence has also become popular in recent years (Goleman, 1995, 1998; Goleman, Boyatzis, & McKee, 2013; Stein & Deonarine, 2015). Some evidence suggests that emotional intelligence is a strong predictor of successful adaptation to new environments (e.g., college or a foreign country) and of success in one's chosen field (Gabel, Dolan, & Cerdin, 2005; Parker et al., 2006; Stein & Book, 2006). A related concept is that of social intelligence. *Social intelligence* is the ability to understand and interact with other people (Albrecht, 2009; Goleman, 2007; Boyatzis, Gaskin, & Wei, 2015; Kihlstrom & Cantor, 2000).

A number of cultural differences are evident in the definition of intelligence. These differences have led to a field of study within intelligence research that examines cultural differences in defining intelligence. This field explores what is termed *cultural intelligence,* or CQ (Ang, Van Dyne, & Tan, 2011; Sternberg & Grigorenko, 2006). This term is used to describe a person's ability to adapt to a variety of challenges in diverse cultures (Ang, Dyne, & Koh, 2006; Sternberg & Grigorenko, 2006; Triandis, 2006). Research also shows that personality variables are related to intelligence (Ackerman, 1996; DeYoung, 2011). Taken together, this evidence suggests that a comprehensive definition of intelligence incorporates many facets of intellect.

Explicit definitions of intelligence also focus on assessment. In fact, some psychologists have been content to define intelligence as whatever it is that the tests measure (Boring, 1923). This definition, unfortunately, is circular. According to it, the nature of intelligence is what is tested. But what is tested must be determined by the nature of intelligence. Moreover, what different tests of intelligence measure is not always the same thing. Different tests measure somewhat different constructs (Daniel, 2000; Kaufman, 2000; Naglieri, 2015). So it is not feasible to define intelligence by what tests measure, as though they all measured the same thing. By the way, the answers to the questions in the chapter opener are as follows:

1. Rubber. Candles are frequently made of tallow, just as tires are frequently made of (c) rubber.
2. 100%, 0.75, and 1⁄2 are quantities that successively decrease by 1⁄4; to complete the series, the answer is (c) one fourth, which is a further decrease by 1⁄4.
3. The first series was a circle and a square, followed by two squares and a circle, followed by three circles and a square; the second series was three triangles and a square, which would be followed by (b), four squares and a triangle.
4. The person you met is clearly a liar. If the girl about whom this person was talking were a truth-teller, she would have said that she was a truth-teller. If she

were a liar, she would have lied and said that she was a truth-teller also. Thus, regardless of whether the girl was a truth-teller or a liar, she would have said that she was a truth-teller. Because the man you met has said that she said she was a liar, he must be lying and hence must be a liar.

Measures and Structures of Intelligence

Contemporary measurements of intelligence usually can be traced to one of two different historical traditions. One tradition concentrated on lower-level, psychophysical abilities. These include sensory acuity, physical strength, and motor coordination. The other focused on higher-level, judgmental abilities. We traditionally describe these abilities as related to thinking, reasoning, and problem solving (Lohman & Lakin, 2011). Stop for a moment to think about yourself and your close associates. How would you assess yourself and your associates in terms of intelligence? When you make these assessments, do psychophysical abilities seem more important? Or do judgment abilities seem more important to you?

Francis Galton (1822–1911) believed that intelligence is a function of psychophysical abilities. For several years, Galton maintained a well-equipped laboratory where visitors could have themselves measured on a variety of psychophysical tests. These tests measured a broad range of psychophysical skills and sensitivities. One example was weight discrimination, the ability to notice small differences in the weights of objects. Another example was pitch sensitivity, the ability to hear small differences between musical notes. A third example was physical strength (Galton, 1883). One of the many enthusiastic followers of Galton attempted to detect links among the assorted tests (Wissler, 1901). He hoped such links would unify the various dimensions of psychophysically based intelligence. But he detected no unifying associations. Moreover, the psychophysical tests did not predict college grades. Thus, the psychophysical approach to assessing intelligence soon faded almost into oblivion. Nevertheless, it would reappear many years later in a somewhat different guise.

An alternative to the psychophysical approach was developed by Alfred Binet (1857–1911). He and his collaborator, Theodore Simon, also attempted to assess intelligence, but their goal was much more practical than purely scientific. Binet had been asked to devise a procedure for distinguishing normal learners from learners who are mentally retarded (Binet & Simon, 1916). Thus, Binet and his collaborator set out to measure intelligence as a function of the ability to learn within an academic setting. In Binet's view, judgment is the key to intelligence; the key, according to Binet, is not psychophysical acuity, strength, or skill.

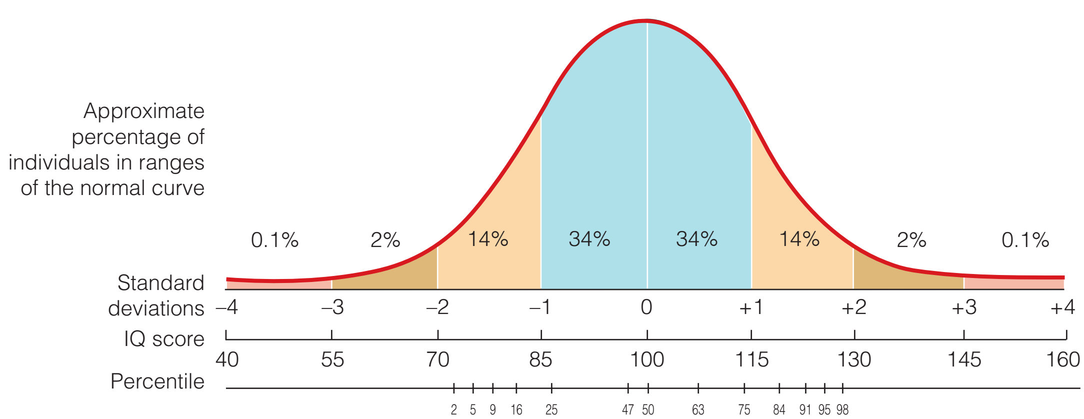
For Binet (Binet & Simon, 1916), intelligent thought (mental judgment) includes three distinct elements: direction, adaptation, and criticism (see Esping & Plucker, 2015). Think about how you are intelligently using these elements yourself at this moment: Direction involves knowing what has to be done and how to do it; adaptation refers to customizing a strategy for performing a task and then monitoring that strategy while implementing it; and criticism is your ability to critique your own thoughts and actions. The importance of direction and adaptation certainly fits with contemporary views of intelligence, and Binet's notion of criticism actually seems prescient, considering the current appreciation of metacognitive processes as a key aspect of intelligence.

Initially, when Binet and Simon developed their intelligence test, they were searching for a way to compare the intelligence of a given child with that of other children of the same chronological (physical) age. For their purposes, they sought to determine each child's *mental age*—the average level of intelligence for a person of a given age. Thus, a mental age of 7 refers to the level of thinking reached by an average 7-year-old child. Mental ages worked just fine for comparing a given 7-year-old child with other 7-year-old children, but the use of mental ages made it difficult to compare relative intelligence in children of differing chronological ages.

William Stern (1912) suggested instead that we evaluate people's intelligence by using an *intelligence quotient* (IQ): a ratio of mental age (MA) divided by chronological age (CA), multiplied by 100 (Figure 13.1 ■). This ratio can be expressed mathematically as follows: IQ = (MA/CA)(100). Thus, if Joan's mental age of 5 equals her chronological age of 5, then her intelligence is average and her IQ is 100 because (5/5)(100) = 100. When mental age exceeds chronological age, the ratio will lead to an IQ score above 100, and when chronological age exceeds mental age, the ratio will lead to an IQ score below 100. Intelligence scores that are expressed in terms of a ratio of mental age to chronological age are termed *ratio IQs*.

For various reasons, ratio IQs proved inadequate. For example, increases in mental age slow down at about age 16 years. An 8-year-old child with a mental age of 12 years is pretty smart. However, do you feel sure that a 40-year-old adult with a mental age of 60 is similarly intelligent, although the ratio IQ is the same for the 8-year-old child and the 40-year-old adult? What does a mental age of 60 mean? In the 21st century, psychologists rarely use IQs based on mental ages. Instead, researchers have turned to measurement comparisons based on assumed normal distributions of test scores within large populations. Scores based on deviations from the middle score in a normal distribution of scores on a test of intelligence are termed *deviation IQs*. Many cognitive theorists believe that IQs provide an incomplete measurement of intelligence, as discussed later in this chapter.

Lewis Terman of Stanford University built on Binet and Simon's work in Europe and constructed the earliest version of what is known as the Stanford–Binet Intelligence Scale (Roid, 2003; Terman & Merrill, 1937, 1973; Thorndike, Hagen, & Sattler, 1986; Table 13.1 ■). For years, the Stanford–Binet test was the standard for intelligence tests, and it still is used widely. More widely used, however, are probably the competitive Wechsler scales, named for their creator, David Wechsler (Benisz, Dumont, & Willis, 2015).



■ **Figure 13.1** This figure shows a normal distribution as it applies to IQ, including identifying labels that are sometimes used to characterize different levels of IQ. It is important not to take these labels too seriously because they only are loose characterizations, not scientific descriptions of performance.

Table 13.1 The Stanford–Binet Intelligence Scale

The sample questions used throughout this chapter are not actual questions from any of the scales; they are intended only to illustrate the types of questions that might appear in each of the main content areas of the tests. How would you respond to these questions? What do your responses indicate about your intelligence?

Content Area	Explanation of Tasks/Questions	Example of a Possible Task/Question
Verbal Reasoning		
Vocabulary comprehension	Define the meaning of a word. Show an understanding of why the world works as it does.	What does the word *diligent* mean? Why do people sometimes borrow money?
Absurdities	Identify the odd or absurd feature of a picture.	Recognize that ice hockey players do not ice skate on lakes into which swimmers in bathing suits are diving.
Verbal relations	Tell how three of four items are similar to one another yet different from the fourth item.	Note that an apple, a banana, and an orange can be eaten, but a mug cannot be.
Quantitative Reasoning		
Number series	Complete a series of numbers.	Given the numbers 1, 3, 5, 7, 9, what number would you expect to come next?
Quantitative	Solve simple arithmetic-word problems.	If Maria has six apples, and she wants to divide them evenly among herself and her two best friends, how many apples will she give to each friend?
Figural/Abstract Reasoning		
Pattern analysis	Figure out a puzzle in which the test-taker must combine pieces representing parts of geometric shapes, fitting them together to form a particular geometric shape.	Fit together these pieces to form a (geometric shape). 
Short-Term Memory		
Memory for sentences	Listen to a sentence; then repeat it back exactly as the examiner said it.	Repeat this sentence back to me: "Harrison went to sleep late and awoke early the next morning."
Memory for digits	Listen to a series of digits (numbers); then repeat the numbers either forward or backward or both.	Repeat these numbers backward: "9, 1, 3, 6."
Memory for objects	Watch the examiner point to a series of objects in a picture; then point to the same objects in exactly the same sequence in which the examiner did so.	Point to the carrot, then the hoe, then the flower, then the scarecrow, and then the baseball. 

Images Source: Sternberg, *Cognitive Psychology*, 5e, Page 534, last column of Table 13.1.

There are three levels of the Wechsler intelligence scales, including the fourth edition of the Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008), the fourth edition of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), and the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III; Wechsler, 2002). Historically, the Wechsler adult tests yielded three scores: a verbal score, a performance score, and an overall score. The verbal score is based on tests such as vocabulary and verbal similarities. In verbal similarities, the test-taker has to say how two things are similar. The performance score is based on several tests. One is picture completion, which requires identification of a missing part in a picture of an object. Another is picture arrangement, which requires rearrangement of a scrambled set of cartoon-like pictures into an order that tells a coherent story. The overall score is a combination of the verbal and the performance scores. More recently (in the fourth edition), the scoring system has been changed to yield a different set of scores more consistent with theorizing in cognitive psychology: verbal comprehension, perceptual reasoning, working memory, and processing speed. Table 13.2 ■ shows the types of items from each of the Wechsler adult-scale subtests, which you may wish to compare with those of the Stanford–Binet.

Wechsler, like Binet, had a conception of intelligence that went beyond what his own test measured. Wechsler clearly believed in the worth of attempting to measure intelligence. But he did not limit his conception of intelligence to test scores. Wechsler believed that intelligence is central in our everyday lives. Intelligence is not represented just by a test score or even by what we do in school. We use our intelligence not only in taking tests and in doing homework but also in relating to people, in performing our jobs effectively, and in managing our lives in general.

A focus on measuring intelligence is only one of several approaches to theory and research on intelligence. Issues related to the approach to studying intelligence are discussed in earlier chapters in this book. One issue is whether cognitive psychologists should focus on the measurement of intelligence or on the processes of intelligence. A second issue is what underlies intelligence: a person's genetic inheritance, a person's acquired attributes, or some kind of interaction between the two. Modern psychologists overwhelmingly accept the notion that intelligence derives from an interaction of genetic and environmental factors (Deary, Johnson, & Houlihan, 2009; Mandelman & Grigorenko, 2011)

Psychologists interested in the structure of intelligence have relied on factor analysis as the indispensable tool for their research. **Factor analysis** is a statistical method for separating a construct—intelligence in this case—into a number of hypothetical factors or abilities that the researchers believe form the basis of individual differences in test performance (Willis, Dumont, & Kaufman, 2011). The specific factors derived, of course, still depend on the specific questions being asked and the tasks being evaluated.

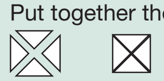
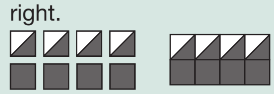
Factor analysis is based on studies of correlation. The idea is that the more highly two tests are correlated, the more likely they are to measure the same thing. In research on intelligence, a factor analysis might involve these steps. First, give a large number of people several different tests of ability. Second, determine the correlations among all of those tests. Third, statistically analyze those correlations to simplify them into a relatively small number of factors that summarize people's performance on the tests. The investigators in this area generally have agreed on and followed this procedure. Yet the resulting factorial structures of intelligence have differed among different theorists. Among the many competing factorial theories, the main ones probably have been those of Spearman, Thurstone, Guilford, Cattell, Vernon, and Carroll (see review in Schneider & Flanagan, 2015). Figure 13.2 ■ contrasts four of these theories.

Spearman: The "g" Factor

Charles Spearman (1863–1945) is credited with inventing factor analysis (Spearman, 1927). Using factor-analytic studies, Spearman concluded that intelligence can be understood in terms of two kinds of factors. A single general factor pervades performance on all tests of mental ability. A set of specific factors is involved in performance on only a single type of mental-ability test (e.g., arithmetic computations). In Spearman's view, the

Table 13.2 The Wechsler Adult Intelligence Scale

Based on the content areas and the kinds of questions shown here, how does the Wechsler differ from the Stanford–Binet?

Content Area	Explanation of Tasks/Questions	Example of a Possible Task/Question
Verbal Scale		
Comprehension	Answer questions of social knowledge.	What does it mean when people say, "A stitch in time saves nine"? Why are convicted criminals put into prison?
Vocabulary	Define the meaning of a word.	What does *persistent* mean? What does *archaeology* mean?
Information	Supply generally known information.	Who is Michelle Obama? What are six New England states?
Similarities	Explain how two things or concepts are similar.	In what ways are an ostrich and a penguin alike? In what ways are a lamp and a heater alike?
Arithmetic	Solve simple arithmetic-word problems.	If Paul has $14.43, and he buys two sandwiches that cost $5.23 each, how much change will he receive? How many hours will it take to travel 1,200 miles if you are traveling 60 miles per hour?
Digit span	Listen to a series of digits (numbers); then repeat the numbers either forward, backward, or both.	Repeat these numbers backward: "9, 1, 8, 3, 6." Repeat these numbers, just as I am telling you: "6, 9, 3, 2, 8."
Performance Scale		
Object assembly	Put together a puzzle by combining pieces to form a particular common object.	Put together these pieces to make something. 
Block design	Use patterned blocks to form a design that looks identical to a design shown by the examiner.	Assemble the blocks at the left to match the design at the right. 
Picture completion	Tell what is missing from each picture.	What is missing from this picture? 
Picture arrangement	Put a set of cartoon-like pictures into chronological order so that they tell a coherent story.	Arrange these pictures in an order that tells a story, and then tell what is happening in the story. 
Digit symbol	When given a key matching particular symbols to particular numerals, use the sequence of symbols to transcribe from symbols to numerals using the key.	Look carefully at the key, showing which symbols correspond to which numerals. In the blanks, write the correct numeral for the symbol above each blank. ○ □ ⊗ ◇ ⊖ / 1 2 3 4 5 □ ◇ ⊖ □ ○ ⊗ ◇ ⊖ / _ _ _ _ _ _ _ _

Images Source: Sternberg, *Cognitive Psychology*, 5e, Page 535, last column of Table 13.2.

specific factors are of only casual interest because of the narrow applicability of these factors. To Spearman, the general factor, which he labeled the **"g" factor**, provides the key to understanding intelligence. Spearman believed "g" to be the result of "mental energy." Many psychologists still believe Spearman's theory to be essentially correct (e.g., Jensen, 1998; see essays in Sternberg & Grigorenko, 2013).

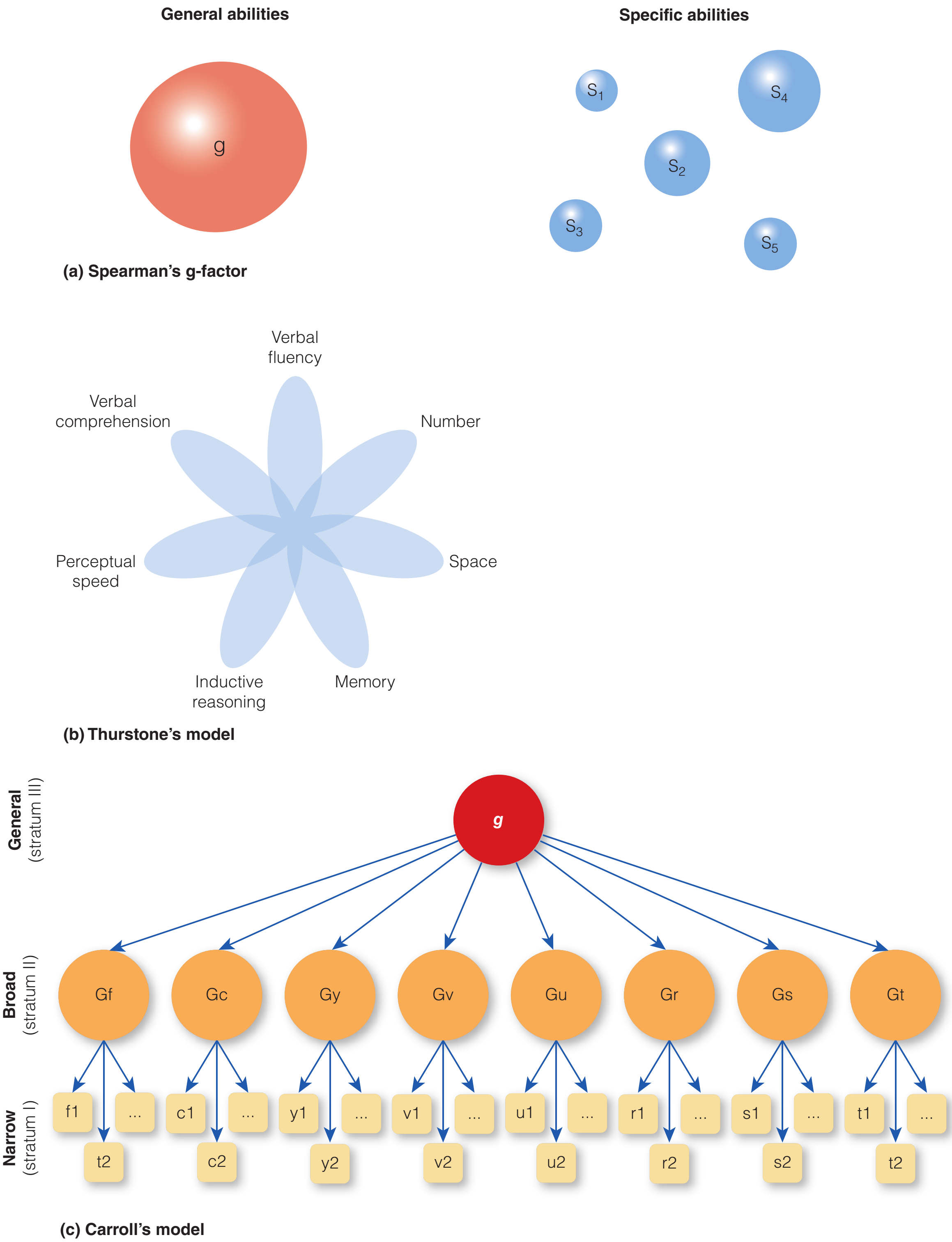


Figure 13.2 Although Spearman, Thurstone, and Carroll all used factor analysis to determine the factors underlying intelligence, they all reached different conclusions regarding the structure of intelligence. Which model most simply yet comprehensively describes the structure of intelligence as you understand it? How do particular models of intelligence shape our understanding of intelligence?

Source: Based on *In Search of the Human Mind*, by Robert J. Sternberg. Copyright © 1995 by Harcourt Brace & Company.

Thurstone: Primary Mental Abilities

In contrast to Spearman, Louis Thurstone (1887–1955) concluded that the core of intelligence resides not in one single factor but in seven such factors (Thurstone, 1938). He referred to them as primary mental abilities. According to Thurstone, the primary mental abilities are as follows:

1. *Verbal comprehension:* measured by vocabulary tests
2. *Verbal fluency:* measured by time-limited tests requiring the test-taker to think of as many words as possible that begin with a given letter
3. *Inductive reasoning:* measured by tests such as analogies and number-series completion tasks
4. *Spatial visualization:* measured by tests requiring mental rotation of pictures of objects
5. *Number:* measured by computation and simple mathematical problem-solving tests
6. *Memory:* measured by picture and word-recall tests
7. *Perceptual speed:* measured by tests that require the test-taker to recognize small differences in pictures or to cross out the differences in strings of varied letters

These components provide a direct means to measure intelligence as defined by Thurstone (1938). The measure of intelligence is still used by some experimenters to assess intellectual abilities (Vigil-Colet & Morales-Vives, 2005).

Cattell, Vernon, and Carroll: Hierarchical Models

An economical way of handling a number of factors of the mind is through a hierarchical model of intelligence. One such model proposed that general intelligence comprises two major subfactors. They are fluid ability and crystallized ability. Fluid ability is speed and accuracy of abstract reasoning, especially for novel problems. Crystallized ability is accumulated knowledge and vocabulary (Cattell, 1971). Subsumed within these two major subfactors are other, more specific factors. A similar view is a general division between practical-mechanical and verbal-educational abilities (Vernon, 1971).

A more recent model is a hierarchy composed of three strata (Carroll, 1993). Stratum I includes many narrow, specific abilities (e.g., spelling ability, speed of reasoning). Stratum II includes various broad abilities (e.g., fluid intelligence, crystallized intelligence). And Stratum III is just a single general intelligence, much like Spearman's "g" factor. Of these strata, the most interesting is the middle stratum, which is neither too narrow nor too all encompassing.

In addition to fluid intelligence and crystallized intelligence, Carroll includes in the middle stratum several other abilities. They are learning and memory processes, visual perception, auditory perception, facile production of ideas (similar to verbal fluency), and speed (which includes both sheer speed of response and speed of accurate responding). Carroll's model is probably the most widely accepted of the psychometric models.

Johnson and Bouchard (2005) proposed a variation of hierarchical theory in which they suggested that abilities are properly divided not into fluid and crystallized, but rather into verbal, perceptual, and image rotation. Their argument is that spatial abilities such as the ability to rotate images of objects in the mind are relatively distinct from either fluid or crystallized intelligence. Whereas the factor-analytic approach this theory exemplifies has tended to emphasize the structures of intelligence, the information-processing approach has tended to emphasize the operations of intelligence.

Information Processing and Intelligence

Information-processing theorists study how people mentally manipulate what they learn and know about the world (Hunt, 2005; Mackintosh, 2011). The ways in which various information-processing investigators study intelligence differ primarily in terms of the complexity of the processes being studied (Lohman & Lakin, 2011; Stankov, 2005). Researchers have considered both the speed and the accuracy of information processing to be important factors in intelligence.

Process-Timing Theories

Inspection time is the amount of time it takes you to inspect items and make a decision about them. It is measured through an inspection-time experimental paradigm (Nettelbeck, 1987, 2011; see also Deary, 2000; Deary & Stough, 1996; Neubauer & Fink, 2005). Here is a typical use of the paradigm. For each of a number of trials, a computer monitor displays a fixation cue (a dot in the area where a target figure will appear) for 500 milliseconds. There is then a pause of 360 milliseconds. Following this period, the computer presents the target stimulus for a particular interval of time. Finally, it presents a visual mask (a stimulus that erases the trace in iconic memory).

The target stimulus typically includes two vertical lines of unequal length. For example, one might be 25 millimeters and the other 35 millimeters. The two lines are aligned at the top by a horizontal crossbar. The shorter of the two lines may appear on either the right or the left side of the stimulus. The visual mask is a pair of lines that are thicker and longer than the two lines of the target stimulus. The task is to inspect the target stimulus and then indicate the side on which the shorter line appeared. One indicates the left-hand stimulus by pressing a left-hand button on a keypad connected to a computer that records the responses. One indicates the right-hand stimulus by pressing the right-hand button.

The key variable is the length of time for the presentation of the target stimulus, not the speed of responding by pressing the button. Nettelbeck defined inspection time operationally. It is the length of time for presentation of the target stimulus after which the participant still responds with at least 90% accuracy in indicating the side on which the shorter line appeared. He found that shorter inspection times correlate with higher scores on intelligence tests (e.g., various subscales of the WAIS) among differing populations of participants (Nettelbeck, 1987, 2011).

Choice Reaction Time

Some investigators have proposed that intelligence can be understood in terms of speed of neuronal conduction (e.g., Jensen, 1979, 1998; see Nettelbeck, 2011). In other words, the smart person is someone whose neural circuits conduct information rapidly. When Arthur Jensen proposed this notion, direct measures of neural-conduction velocity were not readily available. So Jensen primarily studied a proposed proxy for measuring neural-processing speed. The proxy was *choice reaction time*—the time it takes to select one answer from among several possibilities.

Consider a typical choice-reaction-time paradigm. The participant is seated in front of a set of lights on a board (Figure 13.3 ■). When one of the lights flashes, he or she extinguishes it by pressing as rapidly as possible a button beneath the correct light. The experimenter would then measure the participant's speed in performing this task.

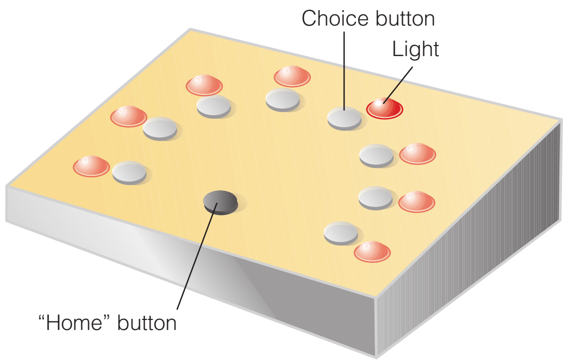


Figure 13.3 To measure choice reaction time, Jensen used an apparatus like the one shown here.

Source: Based on *Bias in Mental Testing* by Arthur R. Jensen. Copyright © 1980 by Arthur R. Jensen. All rights reserved.

Participants with higher IQs are faster than participants with lower IQs in their reaction time (RT; Jensen, 1982). In this particular version of the task, RT is defined as the time between when a light comes on and the finger leaves the home (central) button. In some studies, participants with higher IQs also showed a faster movement time (MT). MT is defined as the time between letting the finger leave the home button and hitting the button under the light. These findings may be due to increased central nerve-conduction velocity, although at present this proposal remains speculative (Reed & Jensen, 1991, 1993).

Research indicates choice RT may be influenced by extraneous factors, including the number of response alternatives and the visual-scanning requirements of Jensen's apparatus. In this case, RT as measured would not be a result of speed of reaction time alone (Bors, MacLeod, & Forrin, 1993). In particular, manipulating the number of buttons and the size of the visual angle of the display (how much of the visual field it consumes) can reduce the correlation between IQ and reaction time (Bors, MacLeod, & Forrin, 1993). Thus, the relation between reaction time and intelligence is unclear.

Lexical-Access Speed and Speed of Simultaneous Processing

Some investigations have focused on *lexical-access speed*—the speed with which we can retrieve information about words (e.g., letter names) stored in our long-term memories (Hunt, 1978). This speed can be measured with a letter-matching, reaction-time task first proposed by Posner and Mitchell in 1967 (Hunt, 1978).

Participants are shown pairs of letters, such as *A A*, *A a*, or *A b*. For each pair, they indicate whether the letters constitute a match in name (e.g., A a match in name of letter of the alphabet but A b do not). They also are given a simpler task. In it, they are asked to indicate whether the letters match physically (e.g., A A are physically identical, whereas A a are not). The variable of interest is the difference between their speed for the first set of tasks, involving name matching, and their speed for the second set, involving matching of physical characteristics. The difference in reaction time between the two kinds of tasks is said to provide a measure of speed of lexical access. This score is based on a *subtraction* of name-match minus physical-match reaction time. The subtraction controls for mere perceptual-processing time. Students with lower verbal ability take longer to gain access to lexical information than do students with higher verbal ability (Hunt, 1978).

Intelligence is also related to people's ability to divide their attention (Hunt & Lansman, 1982). For example, suppose that participants are asked to solve mathematical problems while listening for a tone and to press a button as soon as they hear it. We can expect that they both would solve the math problems effectively and respond quickly to hearing the tone. According to Hunt and Lansman, more intelligent people are better able to timeshare between two tasks and to perform both effectively.

In sum, process-timing theories attempt to account for differences in intelligence by appealing to differences in the speed of various forms of information processing. Inspection time, choice reaction time, and lexical access timing all have been found to correlate with measures of intelligence. These findings suggest that, on average, higher intelligence may be related to the speed of various information-processing abilities. More intelligent people encode information more rapidly into working memory. They access information in long-term memory more rapidly. And they respond more rapidly. Why would more rapid encoding, retrieval, and responding be associated with higher intelligence test scores? Do rapid information processors learn more?

Is there a link between age-related slowing of information processing and (1) initial encoding and recall of information and (2) long-term retention (Nettelbeck et al., 1996)? The relationship between inspection time and intelligence may not be related to learning. In particular, there is a difference between initial recall and actual long-term learning (Nettelbeck et al., 1996). Initial recall performance is mediated by processing speed. Older, slower participants showed deficits. Longer-term retention of new information, preserved in older participants, is mediated by cognitive processes other than speed of processing. These processes include rehearsal strategies. Thus, speed of information processing may influence initial performance on recall and inspection time tasks, but speed is not related to long-term learning. Perhaps faster information processing aids participants in performance aspects of intelligence test tasks, rather than contributing to actual learning and intelligence. Clearly, this area requires more research to determine how information-processing speed relates to intelligence.

Working Memory

Working memory is a critical component of intelligence. Indeed, some investigators have argued that intelligence may be little more than working memory (Conway et al., 2011; Kyllonen & Christal, 1990). In one study, participants read sets of passages and, after they had read the passages, tried to remember the last word of each passage (Daneman & Carpenter, 1983). Recall was highly correlated with verbal ability. In another study, participants performed a variety of working memory tasks. In one task, for example, the participants saw a set of simple arithmetic problems, each of which was followed by a word or a digit. An example would be "Is $(3 \times 5) - 6 = 7$? TABLE" (Turner & Engle, 1989; see also Hambrick, Kane, & Engle, 2005). The participants were given sets of two to six such problems and solved each one. After solving the problems in the set, they tried to recall the words that followed the problems. The number of words recalled was highly correlated with measured intelligence.

Working memory measurements may closely predict scores on tests of general ability (Colom et al., 2004; see also Conway et al. 2011). Other researchers have demonstrated a significant but smaller relationship between working memory and general intelligence (e.g., Ackerman, Beier, & Boyle, 2005). Thus, it appears that the ability to store and manipulate information in working memory may be an important aspect of intelligence. It is probably not all there is to intelligence, however.

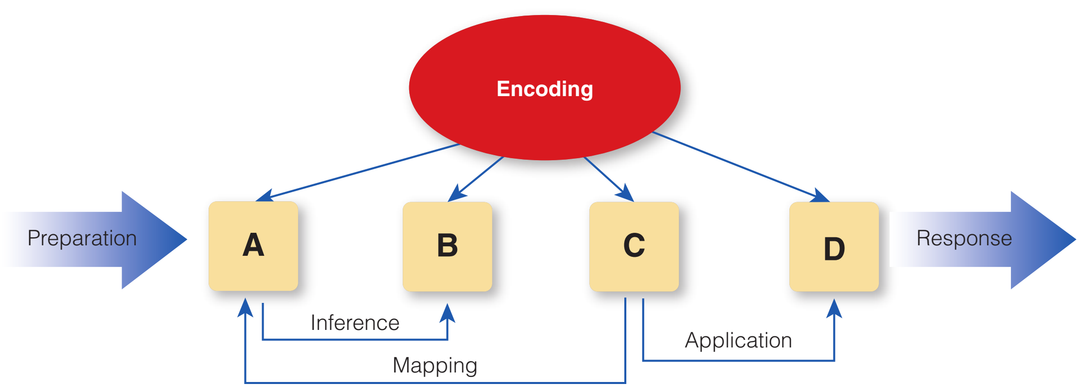
Componential Theory and Complex Problem Solving

Cognitive approaches for studying information processing can be applied to more complex tasks, such as analogies, series problems (e.g., completing a numerical or figural series), and syllogisms (Sternberg, 1977, 1983, 1984; see Chapter 12). The idea is to take the kinds of tasks used on conventional intelligence tests and to isolate components of intelligence. *Components* are the mental processes used in performing these tasks, such as translating a sensory input into a mental representation, transforming one conceptual representation into another, or translating a conceptual representation into a motor output (Sternberg, 1982). Many investigators have elaborated on and expanded this basic approach (Lohman, 2005; Lohman & Lakin, 2011; Wenke, Frensch, & Funke, 2005; see Duggan & Garcia-Barrera, 2015).

Componential analysis breaks down people's reaction times and error rates on these tasks in terms of the processes that make up the tasks. This kind of analysis revealed that people may solve analogies and similar tasks by using several component processes. Among them are several processes. A first is encoding the terms of the problem. A second is inferring relations among at least some of the terms. A third is mapping the inferred relations to other terms, which would be presumed to show similar relations. And a fourth is applying the previously inferred relations to the new situations.

Consider the analogy LAWYER : CLIENT :: DOCTOR : (a. PATIENT, b. MEDICINE). To solve this analogy, you need to *encode* each term of the problem. This includes perceiving a term and retrieving information about it from memory. You then *infer* the relationship between lawyer and client. In particular, the former provides professional services to the latter. You then *map* the relationship in the first half of the analogy to the second half of the analogy. Here, you note that it will involve that same relationship. Finally, you *apply* that inferred relationship to generate the final term of the analogy. This leads to the appropriate response of PATIENT. Figure 13.4 ■ shows how componential analysis would be applied to an analogy problem, A is to B as C is to D, where D is the solution. Studying these components of information processing reveals more than measuring mental speed alone.

There are significant correlations between speed in executing these processes and performance on other, traditional intelligence tests. A more intriguing discovery, however, is that participants who score higher on traditional intelligence tests take longer to encode the terms of the problem than do less intelligent participants. But they make up for the extra time by taking less time to perform the remaining components of the task. In general, more intelligent participants take longer during *global planning*—encoding the problem and formulating a general strategy for attacking the problem (or set of problems). But they take less time for *local planning*—forming and implementing strategies for the details of the task (Sternberg, 1981).



■ **Figure 13.4** In the solution of an analogy problem, the problem solver must first encode the problem A is to B as C is to D. The problem solver then must infer the relationship between A and B. Next, the problem solver must map the relationship between A and B to the relationship between C and each of the possible solutions to the analogy. Finally, the problem solver must apply the relationship to choose which of the possible solutions is the correct solution to the problem.

Source: Sternberg, *Cognitive Psychology* 5e, Page 543, last column of Figure 13.4.

in the lab of **IAN DEARY**

My "lab" consists of a number of attractive, late-Victorian offices in one wing of a building facing George Square gardens at the center of the University of Edinburgh, and human testing locations in the city's teaching hospitals. From these, I oversee the research on the Lothian Birth Cohorts of 1921 and 1936, and the Centre for Cognitive Ageing and Cognitive Epidemiology (CCACE).

Courtesy of Ian Deary

Ian Deary

The fundamental question the lab members are trying to answer is: Why do some people's brains and thinking skills age better than others? We also address an additional question: Why does cognitive ability from early life have a pronounced effect on people's health, illnesses, and survival later in life? The core of the day-to-day work is testing the members of the cohorts. The members of the Lothian Birth Cohort of 1936 are in their late seventies. They are special because they all took the same intelligence test as children and are being followed up on more than 60 years later. They will be tested individually by psychologists and nurses over the period 2015 to 2017. Therefore, the lab's activities are a mixture of intensive and long-term detailed cognitive testing, medical investigations, brain scanning, and genetic tests. My lab is rather unusual for psychology. It does contain some psychologists, but also epidemiologists, geneticists, and brain-imaging experts.

We have regular lab and Centre meetings to ensure that all the testing and day-to-day business is running on course. We also have journal clubs and scientific meetings to ensure, in addition, that the reporting of the work is on course.

With a set of cohorts that has such a wide variety of data, it is also important to have many senior and junior collaborators who bring additional expertise to our team. For example, we have many outside experts who help with aspects of genetics and brain imaging, and also on the many other areas into which the study delves.

In my lab, we have shown that around half of the variance in intelligence is stable from childhood to old age. We were the first lab to report substantial heritability of intelligence based on analysis of DNA in unrelated individuals. We found that the integrity of the brain's white matter accounts for about 10% of the variance in general cognitive ability in older people. We also have found that some factors that were thought to be protective against cognitive decline in older age actually are confounded with childhood intelligence; these include moderate alcohol consumption, coffee drinking, and engagement in sociocultural activities. In other words, what appeared to be the effect of, say, moderate alcohol consumption actually can be traced to the fact that people identified as more intelligent, even from childhood, tend to drink slightly more, although in moderation, and especially red wine. So prior intelligence, rather than moderate alcohol consumption, appears to be the deeper causal variable. We have found, however, some factors that actually might be helpful toward retaining cognitive capability in older age (although the individual effects are small)—for example, not smoking, being more physically fit, and speaking more than one language.

The advantage of spending more time on global planning is the increased likelihood that the overall strategy will be correct. Thus, when taking more time is advantageous, brighter people may take longer to do something than will less bright people. For example, the brighter person might spend more time researching and planning for writing a term paper but less time in the actual writing of it. This same differential in time allocation has been shown in other tasks as well. An example would be in solving physics problems (Larkin et al., 1980; see Sternberg, 1979, 1985a). That is, more intelligent people seem to spend more time planning for and encoding the problems they face. But they spend less time engaging in the other components of task performance. This may relate to the previously mentioned metacognitive attribute many include in their notions of intelligence.

Researchers have studied information processing of people engaged in complex problem-solving situations. Examples include playing chess and performing logical derivations (Newell & Simon, 1972; Simon, 1976; see also Davidson & Sternberg, 2003). For example, a simple, brief task might require the participants first to view an arithmetic or geometric series. Then they must figure out the rule underlying the progression. And finally they must guess what numeral or geometric figure might come next. More complex tasks might include some of those mentioned in Chapter 11 (e.g., the water jugs problems; see Estes, 1982). Can performance on these or other tasks be analyzed at a biological level?

An Integrative Approach

An integrative approach would combine models of various kinds of cognitive functioning as bases for intelligence. In such an approach, four sources of individual differences in intelligence might be detected (Ackerman, 2005). These are (1) breadth of declarative knowledge, (2) breadth of procedural skills, (3) capacity of working memory, and (4) speed of processing. The advantage of this approach is that it does not try to localize individual differences in intelligence as coming from one source. Rather, multiple sources are involved.

Biological Bases of Intelligence

The human brain is the biological basis for human intelligence (Haier, 2011). Early studies, such as those of Karl Lashley, studied the brain to find biological indicators of intelligence and other aspects of mental processes. They were a resounding failure, despite great efforts. As tools for studying the brain have become more sophisticated, however, we are beginning to see the possibility of finding physiological indicators of intelligence. Some investigators believe that we will soon have clinically useful psychophysiological indices of intelligence (e.g., Matarazzo, 1992). But widely applicable indices will be much longer in coming. In the meantime, the biological studies we now have are largely correlational. They show statistical associations between biological and psychometric or other measures of intelligence. They do not establish causal relations.

One line of research looks at the relationship of brain volume to intelligence (see Haier, 2011; Jerison, 2000; Vernon et al., 2000; Witelson, Beresh, & Kiga, 2006). The evidence suggests that, for humans, there is a modest but significant statistical relationship between brain size and intelligence (Hair, 2011). It is difficult to know, however, what to make of this relationship. Greater brain size may cause greater intelligence, greater intelligence may cause greater brain size, or both may be dependent on some third factor. Moreover, it is probably at least as important how efficiently the brain is used than what its size is. For example, on average, men have larger brains than women. But women, on average, have better connections through the corpus callosum of the two hemispheres of the brain. So it is not clear which sex would be, on average, at an advantage. Probably neither would be. It is important to note that the relationship between brain size and intelligence does not hold across species (Hofman, 2015; Jerison, 2000). Rather, what holds seems to be a relationship between intelligence and brain size, relative to the rough general size of the organism.

For now, some of the current studies offer some appealing possibilities. For example, complex patterns of electrical activity in the brain, which are prompted by specific stimuli, appear to correlate with scores on IQ tests (Barrett & Eysenck, 1992). Several studies initially suggested that speed of conduction of neural impulses may correlate with intelligence, as measured by IQ tests (McGarry-Roberts, Stelmack, & Campbell, 1992; Vernon & Mori, 1992). A follow-up study, however, failed to find a strong relation between neural-conduction velocity and intelligence (Wickett & Vernon, 1994). In this study, conduction velocity was measured by neural-conduction speeds in a main nerve of the arm. Intelligence was measured by a Multidimensional Aptitude Battery. Surprisingly, neural-conduction velocity appears to be a more powerful predictor of IQ scores for men than for women. So sex differences may account for some of the differences in the data (Wickett & Vernon, 1994). Additional studies on both males and females are needed.

More recent work suggests it may be the flexibility of neural circuitry, rather than speed of conduction, that is key (Newman & Just, 2005). Hence, we would want to study not just speed but also neural circuitry. An alternative approach to studying the brain suggests that neural efficiency may be related to intelligence (Li et al., 2009; Neubauer & Fink, 2009). Such an approach is based on studies of how the brain metabolizes glucose (a simple sugar required for brain activity) during mental activities. (See Chapter 2 for more on positron emission tomography and other brain-imaging techniques.) Higher intelligence correlates with reduced levels of glucose metabolism during problem-solving tasks (Haier et al., 1992; Haier & Jung, 2007). That is, smarter brains consume less sugar and hence expend less effort than do less smart brains doing the same task. Furthermore, cerebral efficiency increases as a result of learning on a relatively complex task involving visuospatial manipulations, such as the computer game Tetris (Haier et al., 1992). As a result of practice, more intelligent participants not only show lower cerebral glucose metabolism overall but also show more specifically localized metabolism of glucose. In most areas of their brains, smarter participants show less glucose metabolism. But in selected areas of their brains, believed to be important to the task at hand, they show higher levels of glucose metabolism. Thus, more intelligent participants may have learned how to use their brains more efficiently. They carefully focus their thought processes on a given task.

Other research, however, suggests that the relationship between glucose metabolism and intelligence may be more complex (Haier et al., 1995; Larson et al., 1995). On the one hand, one study confirmed the earlier findings of increased glucose metabolism in less smart participants, in this case, participants who were mildly intellectually disabled (Haier et al., 1995). On the other hand, another study found, contrary to the earlier findings, that smarter participants had increased glucose metabolism relative to their average comparison group (Larson et al., 1995).

There was a problem with earlier studies. It was that the tasks participants received were not matched for difficulty level across groups of smart and average individuals. The study by Larson et al. used tasks that were matched to the ability levels of the smarter and average participants. They found that the smarter participants used more glucose. Moreover, the glucose metabolism was highest in the right hemisphere of the more intelligent participants performing the hard task. These results again suggest selectivity of brain areas. What could be driving the increases in glucose metabolism? Currently, the key factor appears to be subjective task difficulty. In earlier studies, smarter participants simply found the tasks to be too easy. Matching task difficulty to participants' abilities seems to indicate that smarter participants increase glucose metabolism when the task demands it. The preliminary findings in this area will need to be investigated further before any conclusive answers arise.

Some neuropsychological research suggests that performance on intelligence tests may not fully indicate a crucial aspect of intelligence. This is the ability to set goals, to plan how to meet them, and to execute those plans (Dempster, 1991). Specifically, people with lesions on the frontal lobe of the brain frequently perform quite well on standardized IQ tests. These tests require responses to questions within a highly structured situation. But they do not require much in the way of goal setting or planning. These tests frequently use what could be classified as crystallized intelligence. Damage to the posterior regions of the brain seems to have negative effects on measures of crystallized intelligence (Gray & Thompson, 2004; Kolb & Whishaw, 1996; Piercy, 1964). In patients with frontal lobe damage, impairments in fluid intelligence is observed (Duncan, Burgess, & Emslie, 1995; Gray, Chabris, & Braver, 2003; Gray & Thompson, 2004). This result should come as no surprise, given that the frontal lobes are involved in reasoning, decision making, and problem solving (see Chapters 10 and 11). Other research highlights the importance of the parietal regions for performance on general and fluid intelligence tasks (Colom et al., 2009; Lee et al., 2006). Intelligence involves the ability to learn from experience and to adapt to the surrounding environment (Greenwood, 2015). Thus, the ability to set goals and to design and implement plans cannot be ignored. An essential aspect of goal setting and planning is the ability to attend appropriately to relevant stimuli. Another related ability is that of ignoring or discounting irrelevant stimuli.

The discovered importance of the frontal and parietal regions in intelligence tasks has led to the development of an integrated theory of intelligence that highlights the importance of these areas. This theory, called the parietal-frontal integration theory (P-FIT), stresses the importance of interconnected brain regions in determining differences in intelligence. The regions this theory focuses on are the Brodmann areas, the prefrontal cortex, the inferior and superior parietal lobule, the anterior cingulate, and portions of the temporal and occipital lobes (Jung & Haier, 2007). P-FIT describes patterns of brain activity in people with different levels of intelligence; it cannot, however, explain what makes a person intelligent or what intelligence is.

We cannot realistically study a brain or its contents and processes in isolation without also considering the entire human being. We must consider the interactions of that human being with the entire environmental context within which the person acts intelligently. Hence, many researchers and theorists urge us to take a more contextual view of intelligence. Furthermore, some alternative views of intelligence attempt to broaden the definition of intelligence to be more inclusive of people's varied abilities.

Alternative Approaches to Intelligence

Cultural Context and Intelligence

According to **contextualism**, intelligence must be understood in its real-world context. The context of intelligence may be viewed at any level of analysis. It may be focused narrowly, as on the home and family environment, or it may be extended broadly, to entire cultures. For example, even cross-community differences have been correlated with differences in performance on intelligence tests. Such context-related differences include those of rural versus urban communities, low versus high proportions of teenagers to adults within communities, and low versus high socioeconomic status of communities (see Barnett et al., 2011; Coon, Carey, & Fulker, 1992). Contextualists have been intrigued particularly by the effects of cultural context on intelligence.

Contextualists consider intelligence to be inextricably linked to culture (Ang, Van Dyne, & Tan, 2011). They view intelligence as something that a culture creates to define the nature of adaptive performance in that culture. It further accounts for why some people perform better than others on the tasks that the culture happens to value (Sternberg, 2004). Theorists who endorse this model study just how intelligence relates to the external world in which the model is being applied and evaluated. In general, definitions and theories of intelligence will more effectively encompass cultural diversity by broadening in scope. Before exploring some of the contextual theories of intelligence, we will look at what prompted psychologists to believe that culture might play a role in how we define and assess intelligence.

Culture is defined here as "the set of attitudes, values, beliefs and behaviors shared by a group of people, communicated from one generation to the next via language or some other means of communication" (Barnouw, 1985, as cited in Matsumoto, 1994, p. 4). One reason to study culture and intelligence is that they are so inextricably interlinked. Indeed, Tomasello (2001) has argued that culture is what, in large part, separates human from animal intelligence (see also Mandalaywala, Fleener, & Maestripieri, 2015; Zentall, 2011, 2015). Humans have evolved as they have, he believes, in part because of their cultural adaptations, which in turn develop from their ability, even in infancy from about 9 months onward, to understand others as intentional agents.

Many research programs demonstrate the potential hazards of single-culture research. For example, Greenfield (1997) found that it means a different thing to take a test among Mayan children than it does among most children in the United States. The Mayan expectation is that collaboration is permissible and that it is rather unnatural *not* to collaborate. Such a finding is consistent with the work of Markus and Kitayama (1991), which suggests different cultural constructions of the self in individualistic versus collectivistic cultures. Indeed, Nisbett (2003) has found that some cultures, especially Asian ones, tend to be more dialectical in their thinking, whereas other cultures, such as European and North American ones, tend to be more linear. Similarly, people from Asian cultures tend to take a different viewpoint than Westerners when approaching a new object (Nisbett & Masuda, 2003). In general, people from Western cultures tend to process objects independently of the context, whereas people from many Eastern cultures process objects in conjunction with the surrounding context (Nisbett, 2004; Nisbett & Miyamoto, 2005). In fact, some evidence suggests that culture influences many cognitive processes, including intelligence (Lehman, Chiu, & Schaller, 2004). As a result, individuals in different cultures may construct concepts in quite different ways, rendering results of concept-formation or identification studies in a single culture suspect (Atran, 1999; Coley et al., 1999; Medin & Atran, 1999). Thus, groups may think about what appears superficially to be the same phenomenon—whether a concept or the taking of a test—differently. What appear to be differences in general intelligence may in fact be differences in cultural properties (Helms-Lorenz, Van de Vijver, & Poortinga, 2003). Helms-Lorenz et al. (2003) have argued that measured differences in intellectual performance may result from differences in cultural complexity; however, complexity of a culture is extremely hard to define, and what appears to be simple or complex from the point of view of one culture may appear different from the point of view of another.

People in different cultures may have quite different ideas of what it means to be smart. For example, one of the more interesting cross-cultural studies of intelligence was performed by Michael Cole and his colleagues (Cole et al., 1971). These investigators asked adult members of the Kpelle tribe in Africa to sort terms representing concepts. Consider what happens in Western culture when adults are given a sorting task on an intelligence test. More intelligent people typically will sort hierarchically. For example, they may sort names of different kinds of fish together. Then they place the word *fish* over that. They place the name *animal* over *fish* and over *birds,* and so on. Less intelligent people will typically sort functionally. They may sort *fish* with *eat,* for example. Why? Because we eat fish. Or they may sort *clothes* with *wear* because we wear clothes. The Kpelle sorted functionally. They did so even after investigators unsuccessfully tried to get the Kpelle spontaneously to sort hierarchically.

Finally, in desperation, one of the experimenters (Glick) asked a Kpelle to sort as a foolish person would sort. In response, the Kpelle quickly and easily sorted hierarchically.

The Kpelle had been able to sort this way all along. They just had not done it because they viewed it as foolish. And they probably considered the questioners rather unintelligent for asking such stupid questions.

The Kpelle people are not the only ones who might question Western understandings of intelligence. In the Puluwat culture of the Pacific Ocean, for example, sailors navigate incredibly long distances. They do not use the navigational aids that sailors from technologically advanced countries would need to get from one place to another (Gladwin, 1970). Suppose Puluwat sailors were to devise intelligence tests for us and our fellow Americans. We and our compatriots might not seem very intelligent. Similarly, the highly skilled Puluwat sailors might not do well on American-crafted tests of intelligence. These and other observations have prompted quite a few theoreticians to recognize the importance of considering cultural context when intelligence is assessed.

One study provides an example a little closer to home regarding the effects of cultural differences on intelligence tests (Sarason & Doris, 1979). It tracked the IQs of an immigrant population: Italian Americans. Less than a century ago, first-generation Italian-American children showed a median IQ of 87 (low average; range 76–100). Their IQs were relatively low even when nonverbal measures were used and when so-called mainstream American attitudes were considered. Some social commentators and intelligence researchers of the day pointed to heredity and other nonenvironmental factors as the basis for the low IQs. Even in the 21st century, some commentators do the same for other minority groups (Herrnstein & Murray, 1994).

For example, a leading researcher of the day, Henry Goddard, pronounced that 79% of immigrant Italians were "feebleminded." He also asserted that about 80% of immigrant Jews, Hungarians, and Russians were similarly unendowed (Eysenck & Kamin, 1981). Goddard (1917) also asserted that moral decadence was associated with this deficit in intelligence. He recommended that the intelligence tests he used be administered to all immigrants and that all those he deemed substandard would be excluded from entering the United States. But subsequent generations of Italian-American students who take IQ tests today show slightly above-average IQs (Ceci, 1991). Other immigrant groups that Goddard had denigrated have shown similar "amazing" increases. Even the most fervent hereditarians would be unlikely to attribute such remarkable gains in so few generations to heredity. Cultural assimilation, including integrated education, seems a much more plausible explanation.

The preceding arguments may make it clear why it is so difficult to come up with a test that everyone would consider **culture-fair**—equally appropriate and fair for members of all cultures. If members of different cultures have different ideas of what it means to be intelligent, then the very behaviors that may be considered intelligent in one culture may be considered unintelligent in another. Take, for example, the concept of mental quickness. In mainstream U.S. culture, quickness usually is associated with intelligence. To say someone is "quick" is to say that the person is intelligent. Indeed, most group tests of intelligence are strictly timed. Even on individual tests of intelligence, the test-giver times some responses of the test-taker. For example, one set of researchers observed a positive relationship between measures of quickness and scores on the Graduate Record Examinations (GREs; Powers & Kaufman, 2004). Many information-processing theorists and even psychophysiological theorists study intelligence as a function of mental speed.

In many cultures of the world, however, quickness is not at a premium. In these cultures, people may believe that more intelligent people do not rush into things. Even in our own culture, no one will view you as brilliant if you rush things that should not be rushed. For example, it generally is not smart to decide on a marital partner, a job, or a place to live in the 20 to 30 seconds you normally might have to solve an intelligence-test problem.

Intricate patterns on Moroccan rugs were more easily remembered by Moroccan rug merchants than by Westerners. In contrast, Westerners more easily remembered information unfamiliar to Moroccan rug merchants.

Because perfectly culture-fair intelligence tests do not exist, how should we consider context when assessing intelligence? Several researchers have suggested that providing culture-relevant tests is possible (e.g., Baltes, Dittmann-Kohli, & Dixon, 1984; Jenkins, 1979; Keating, 1984). **Culture-relevant tests** measure skills and knowledge that relate to the cultural experiences of the test-takers. Baltes, Dittmann-Kohli, and Dixon (1984), for example, have designed tests measuring skill in dealing with the pragmatic aspects of everyday life. Designing culture-relevant tests requires creativity and effort, but it is probably not impossible. For example, one study investigated memory abilities—one aspect of intelligence as our culture defines it—in our culture versus the Moroccan culture (Wagner, 1978). It found that the level of recall depended on the content that was being remembered. Culture-relevant content was remembered more effectively than nonrelevant content. For example, when compared with Westerners, Moroccan rug merchants were better able to recall complex visual patterns on black-and-white photos of Oriental rugs. Sometimes tests just are not designed to minimize the effects of cultural differences. In such cases, the key to culture-specific differences in memory may be the knowledge and use of metamemory strategies, rather than actual structural differences in memory (e.g., memory span and rates of forgetting; Wagner, 1978).

Research has shown that rural Kenyan school children have substantial knowledge about natural herbal medicines. Western children, of course, would not be able to identify any of these medicines (Sternberg et al., 2001; Sternberg & Grigorenko, 1997). In short, making a test culturally relevant appears to involve much more than just removing specific linguistic barriers to understanding.

Similar context effects appear in children's and adults' performances on a variety of tasks. Three kinds of context affect performance (Ceci & Roazzi, 1994). The first is the social context. An example would be whether a task is considered masculine or feminine. The second is the mental context. An example would be whether a visuospatial task involves buying a home or burgling it. The third is the physical context. Here, an example would be whether a task is presented at the beach or in a laboratory. For example, 14-year-old boys performed poorly on a task when it was couched as a cupcake-baking task, but they performed well when it was framed as a battery-charging task (Ceci & Bronfenbrenner, 1985). Brazilian maids had no difficulty with proportional reasoning when hypothetically purchasing food, but they had great difficulty with it when hypothetically purchasing medicinal herbs (Schliemann & Magalhües, 1990). Brazilian children whose poverty had forced them to become street vendors showed no difficulty in performing complex arithmetic computations when selling things, but they had great difficulty performing similar calculations in a classroom (Carraher, Carraher, & Schliemann, 1985). Thus, test performance may be affected by the context in which the test terms are presented. The extent to which the context of performance resembles the context of learning of an intelligent action may partially determine the extent to which the behavior shows transfer from the first situation to the second (Barnett & Ceci, 2005).

In these studies, the investigators looked at the interaction of cognition and context. Several investigators have proposed theories that seek explicitly to examine this interaction within an integrated model of many aspects of intelligence. Such theories view intelligence as a complex system and are discussed in the next two sections.

Table 13.3 Gardner's Eight Intelligences

On which of Howard Gardner's eight intelligences do you show the greatest ability? In what contexts can you use your intelligences most effectively (after Gardner, 1999)?

Type of Intelligence	Tasks Reflecting this Type of Intelligence
Linguistic intelligence	Used in reading a book; writing a paper, a novel, or a poem; and understanding spoken words
Logical-mathematical intelligence	Used in solving math problems, in balancing a checkbook, in solving a mathematical proof, and in logical reasoning
Spatial intelligence	Used in getting from one place to another, in reading a map, and in packing suitcases in the trunk of a car so that they all fit into a compact space
Musical intelligence	Used in singing a song, composing a sonata, playing a trumpet, or even appreciating the structure of a piece of music
Bodily-kinesthetic intelligence	Used in dancing, playing basketball, running a mile, or throwing a javelin
Interpersonal intelligence	Used in relating to other people, such as when we try to understand another person's behavior, motives, or emotions
Intrapersonal intelligence	Used in understanding ourselves—the basis for understanding who we are, what makes us tick, and how we can change ourselves, given our existing constraints on our abilities and our interests
Naturalist intelligence	Used in understanding patterns in nature

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Gardner: Multiple Intelligences

Howard Gardner (1983, 1993b, 2006; Davis et al., 2011) proposed a **theory of multiple intelligences**, in which intelligence includes multiple independent constructs, not just a single, unitary construct. However, instead of speaking of multiple abilities that together constitute intelligence (e.g., Thurstone, 1938), this theory distinguishes eight distinct intelligences that are alleged to be relatively independent of each other (Table 13.3). Each intelligence is a separate system of functioning, although these systems can interact to produce what we see as intelligent performance. Looking at Gardner's list of intelligences, you might want to evaluate your own intelligences, perhaps rank ordering your strengths in each.

In some respects, Gardner's theory sounds like a factorial one. It specifies several abilities that are construed to reflect intelligence of some sort. Gardner, however, views each ability as a separate intelligence, not just as a part of a single whole. Moreover, a crucial difference between Gardner's theory and factorial ones is in the sources of evidence Gardner used to identify the eight intelligences. Gardner used converging operations, gathering evidence from multiple sources and types of data. In particular, Gardner's theory uses eight "signs" as criteria for detecting the existence of a discrete kind of intelligence:

1. Potential isolation by brain damage. The destruction or sparing of a discrete area of the brain (e.g., areas linked to verbal aphasia) may destroy or spare a particular kind of intelligent behavior.
2. The existence of exceptional individuals (e.g., musical or mathematical prodigies). They demonstrate extraordinary ability (or deficit) in a particular kind of intelligent behavior.

Howard Gardner.

3. An identifiable core operation or set of operations (e.g., detection of relationships among musical tones). It is essential to performance of a particular kind of intelligent behavior.
4. A distinctive developmental history leading from novice to master. It is accompanied by disparate levels of expert performance (i.e., varying degrees of expressing this type of intelligence).
5. A distinctive evolutionary history. Increases in intelligence plausibly may be associated with enhanced adaptation to the environment.
6. Supportive evidence from cognitive-experimental research. An example would be task-specific performance differences across discrete kinds of intelligence (e.g., visuospatial tasks versus verbal tasks). They would need to be accompanied by cross-task performance similarities within discrete kinds of intelligence (e.g., mental rotation of visuospatial imagery and recall memory of visuospatial images).
7. Supportive evidence from psychometric tests indicating discrete intelligences (e.g., differing performance on tests of visuospatial abilities versus on tests of linguistic abilities).
8. Susceptibility to encoding in a symbol system (e.g., language, math, musical notation) or in a culturally devised arena (e.g., dance, athletics, theater, engineering, or surgery as culturally devised expressions of bodily-kinesthetic intelligence). (Gardner, 1983, pp. 63–67)

Gardner does not dismiss entirely the use of psychometric tests. But the base of evidence used by Gardner does not rely on the factor analysis of various psychometric tests alone. In thinking about your own intelligences, how fully integrated do you believe them to be? How much do you perceive each type of intelligence as depending on any of the others?

Gardner's view of the mind is modular. Modularity theorists believe that different abilities—such as Gardner's intelligences—can be isolated as emanating from distinct portions or modules of the brain. Thus, a major task of existing and future research on intelligence is to isolate the portions of the brain responsible for each of the intelligences. Gardner has speculated as to at least some of these locales, but hard evidence for the existence of these separate intelligences has yet to be produced. Furthermore, some scientists question the strict modularity of Gardner's theory (Nettelbeck & Young, 1996). Consider the phenomenon of preserved specific cognitive functioning in autistic savants. Savants are people with severe social and cognitive deficits but with corresponding high ability in a narrow domain. They suggest that such preservation fails as evidence for modular intelligences. The narrow long-term memory and specific aptitudes of savants may not really be intelligent (Nettelbeck & Young, 1996). Thus, there may be reason to question the intelligence of inflexible modules.

Sternberg: The Triarchic Theory

Whereas Gardner emphasizes the separateness of the various aspects of intelligence, Robert Sternberg tends to emphasize the extent to which they work together in the triarchic theory of human intelligence (Sternberg, 1985a, 1996b, 2011). According to the **triarchic theory of human intelligence**, intelligence is composed of three aspects, dealing with the relation of intelligence (1) to the internal world of the person, (2) to experience, and (3) to the external world. Figure 13.5 ■ illustrates the parts of the theory and their interrelations.

How Intelligence Relates to the Internal World

The internal part of the theory emphasizes the processing of information. Information processing can be viewed in terms of three different kinds of components. First are metacomponents—higher-order executive processes (i.e., metacognition) used to plan,

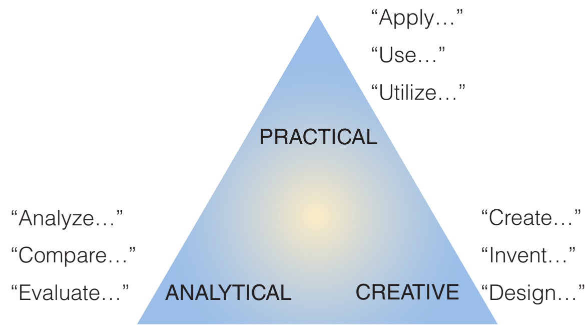

Figure 13.5 According to Robert Sternberg, intelligence comprises analytical, creative, and practical abilities. In analytical thinking, we try to solve familiar problems by using strategies that manipulate the elements of a problem or the relationships among the elements (e.g., comparing, analyzing); in creative thinking, we try to solve new kinds of problems that require us to think about the problem and its elements in a new way (e.g., inventing, designing); and in practical thinking, we try to solve problems that apply what we know to everyday contexts (e.g., applying, using).

monitor, and evaluate problem solving. Second are performance components—lower-order processes used to implement the commands of the metacomponents. And third are knowledge-acquisition components—the processes used for learning how to solve the problems in the first place. The components are highly interdependent.

Suppose that you were asked to write a term paper. You would use metacomponents for higher-order decisions. Thus, you would use them to decide on a topic, plan the paper, monitor the writing, and evaluate how well your finished product succeeds in accomplishing your goals for it. You would use knowledge-acquisition components for research to learn about the topic. You would use performance components for the actual writing. In practice, the three kinds of components do not function in isolation. Before actually writing the paper, you first would have to decide on a topic. Then you would have to do some research. Similarly, your plans for writing the paper might change as you gather new information. It may turn out that there is not enough information on particular aspects of the chosen topic. This scarcity of information may force you to shift your emphasis. Your plans also may change if particular aspects of the writing go more smoothly than others.

How Intelligence Relates to Experience

The theory also considers how prior experience may interact with all three kinds of information-processing components. That is, each of us faces tasks and situations with which we have varying levels of experience. They range from a completely novel task, with which we have no previous experience, to a completely familiar task, with which we have vast, extensive experience. As a task becomes increasingly familiar, many aspects of the task may become *automatic*. They require little conscious effort to determine what step to take next and how to implement that next step. A novel task makes demands on intelligence different from those of a task for which automatic procedures have been developed.

How Intelligence Relates to the External World

The triarchic theory also proposes that the various components of intelligence are applied to experience to serve three functions in real-world contexts:

- The first is adapting ourselves to our existing environments.
- The second is shaping our existing environments to create new environments.
- And the third is selecting new environments.

You use adaptation when you learn the ropes in a new environment and try to figure out how to succeed in it. For example, when you first started college, you probably tried to figure out the explicit and implicit rules of college life. You then try to use these rules to succeed in the new environment. You also shape your environment. For example, you may decide what courses to take and what activities to pursue. You even may try to shape the behavior of those around you, perhaps by starting a new campus organization or by running for student government. Finally, if you are unable either to adapt yourself or to shape your environment to suit you, you might consider selecting another environment. For example, you might transfer to a different college.

According to the triarchic theory, people may apply their intelligence to many different kinds of problems. For example, some people may be more intelligent in the face of abstract, academic problems. Others may be more intelligent in the face of concrete, practical problems. An intelligent person does not necessarily excel in all aspects of intelligence. Rather, intelligent people know their strengths and weaknesses. They find ways in which to capitalize on their strengths and either to compensate for or to correct their weaknesses. For example, a person who is strong in psychology but not in physics might choose as a physics project the creation of a physics aptitude test (which Sternberg did when he took physics). The point is to make the most of your strengths and to find ways to improve on or at least to live comfortably with your weaknesses.

We (Sternberg and colleagues) performed a comprehensive study testing the validity of the triarchic theory and its usefulness in improving performance. We predicted that matching students' instruction and assessment to their abilities would lead to improved performance (Sternberg et al., 1996; Sternberg et al., 1999). Students were selected for one of five ability patterns: high only in analytical ability, high only in creative ability, high only in practical ability, high in all three abilities, or not high in any of the three abilities. Then students were assigned at random to one of four instructional groups. They emphasized either memory-based, analytical, creative, or practical learning. Then the memory-based, analytical, creative, and practical achievement of all students was assessed. We found that students who were placed in an instructional condition that matched their strength in terms of pattern of ability outperformed students who were mismatched. Thus, the prediction of the experiment was confirmed. For example, a high-analytical student being placed in an instructional condition that emphasized analytical thinking outperformed a high-analytical student being placed in an instructional condition that emphasized practical thinking.

Teaching students to use all of their analytic, creative, and practical abilities has resulted in improved school achievement for some students, whatever their ability pattern (Grigorenko, Jarvin, & Sternberg, 2002; Sternberg & Grigorenko, 2004; Sternberg, Torff, & Grigorenko, 1998), but not for all students (Sternberg et al., 2014).

One attempt to broaden the assessment can be seen through the Rainbow Project and related studies (Sternberg, 2010). In the Rainbow Project, students completed the SAT and additional assessments. These additional assessments measured creative and practical abilities as well as of analytical abilities (Sternberg & the Rainbow Project Collaborators, 2006). The addition of these supplemental assessments resulted in superior prediction of college grade point average (GPA) as compared with scores on the SAT and high school GPA. In fact, the new tests doubled the prediction of first-year college GPA obtained just by the SAT. Moreover, the new assessments substantially reduced differences in scores among members of diverse ethnic groups.

Thus far, we have described various models of human intelligence. These models do not, in themselves, state whether intelligence can be taught or improved through instruction. A number of investigators have addressed this issue, however. Can intelligence actually be modified with instruction, and if so, how? What strategies are effective, and which ones, less so? Consider the answers.

practical applications of COGNITIVE PSYCHOLOGY

Intelligence and Culture

Robert L. Williams developed a test he called the BITCH Test (Black Intelligence Test of Cultural Homogeneity). Many "standard" intelligence tests rely heavily on vocabulary (e.g., the Shipley Test, a major section on the Wechsler intelligence tests). Williams scored very poorly on an intelligence test when he was in high school, so he was advised not to go to college but to develop trade skills. Because Williams knew he had "street smarts," he ignored this advice, went to college, and eventually earned his PhD. To demonstrate that knowledge of vocabulary does not capture all of what goes into intelligence, Williams' BITCH test asked people to define various "black" terms of the time, such as "alley apple," "deuce-and-a-quarter," and "Mother's Day." Not surprisingly, most blacks did better on this test than their white counterparts. The items on the test were culturally relevant to most blacks at the time (many of the terms are outdated now), and they were culturally irrelevant to most whites.

Improving Intelligence: Effective, Ineffective, and Questionable Strategies

Human intelligence is malleable—up to a point. It can be shaped and even increased through various kinds of interventions (Detterman & Sternberg, 1982; Grotzer & Perkins, 2000; Jaeggi et al., 2008; Sternberg et al., 1997). The malleability of intelligence is not genetically based (Sternberg, 1997). An attribute, such as height, can be partly or even largely genetically based and yet can be environmentally malleable.

Abundant evidence indicates that a variety of factors can affect intellectual skills. One factor is people's environments (Ceci, Nightingale, & Baker, 1992; Reed, 1993; Sternberg & Wagner, 1994). Another is their motivation (Collier, 1994; Sternberg & Ruzgis, 1994). A third is their training (Feuerstein, 1980; Sternberg, 1987b). Although environmental factors matter, heredity certainly plays a role in individual differences in intelligence (Loehlin, Horn, & Willerman, 1997; Plomin, 1997; Plomin et al., 2012), as does the environment (Sternberg & Grigorenko, 1999; Wahlsten & Gottlieb, 1997). Genetic inheritance may set some kind of upper limit on how intelligent a person may become. We now know, however, that for any attribute that is partly genetic, there is a *reaction range.* This is the range of broad limits of possibilities in which an attribute can be expressed in various ways. Thus, each person's intelligence can be developed further within this broad range of potential intelligence (Grigorenko, 2000). We have no reason to believe that people now reach their upper limits in the development of their intellectual skills. To the contrary, the evidence suggests that we can do quite a bit to help people become more intelligent (for further discussion of these issues, see Mayer, 2000a; Sternberg, 1995; see also Neisser et al., 1996).

Improving Children's Intelligence

The Head Start program was initiated in the 1960s to provide preschoolers with an edge on intellectual abilities and accomplishments when they started school. Long-term follow-up studies have indicated that by mid-adolescence, children who participated in the program were more than a grade ahead of matched controls who did not receive the program (Lazar & Darlington, 1982; Zigler & Berman, 1983). The children in the program also scored higher on a variety of tests of scholastic achievement. They were also less likely to need remedial attention. And they were less likely to show behavioral problems. Although such measures are not truly measures of intelligence, they show strong positive correlations with intelligence tests.

An alternative to intellectual enrichment outside the home may be to provide an enriched home environment. A particularly successful project has been the Abecedarian Project. It showed that the cognitive skills and achievements of lower socioeconomic status children could be increased through carefully planned and executed interventions (Ramey & Ramey, 2000). For instance, children who took part in the Abecedarian program completed more years of postsecondary education than did their nonexperimental peers (Campbell et al., 2002). In another study utilizing portions of the Abecedarian program with low-birth-weight children, early intervention also produced improvements in a number of skills, including ones measured in math and reading tasks (McCormick et al., 2006).

INVESTIGATING COGNITIVE PSYCHOLOGY

Teaching Intelligence

A number of training programs have shown some success. One such program is Reuven Feuerstein's (1980) Instrumental Enrichment program. It involves training in a variety of abstract-reasoning skills. It appears to be particularly effective for improving the skills of performers who have mental disabilities. Another program, the Odyssey program (see Adams, 1986), was shown to be effective in raising the intellectual performance of Venezuelan children of junior high school age. The Philosophy for Children program (Lipman, Sharp, & Oscanyan, 1980) also was shown to teach logical-thinking skills to children throughout the primary and secondary levels of schooling. Aspects of the Intelligence Applied program (Sternberg, 1986; Sternberg & Grigorenko, 2002a; Sternberg, Kaufman, & Grigorenko, 2008) for teaching intellectual skills have been shown to be effective. This program can improve both insight skills (Davidson & Sternberg, 1984) and the ability to learn meanings of words from context, a primary means for acquiring new vocabulary (Sternberg, 1987a). Practical intelligence also can be taught (Gardner et al., 1994; Sternberg, Okagaki, & Jackson, 1990).

Several factors in the early (preschool) home environment appear to be correlated with high IQ scores (Bradley & Caldwell, 1984). They are emotional and verbal responsivity of the primary caregiver and the caregiver's involvement with the child, avoidance of restriction and punishment, organization of the physical environment and activity schedule, provision of appropriate play materials, and opportunities for variety in daily stimulation. Furthermore, Bradley and Caldwell found that these factors more effectively predicted IQ scores than did socioeconomic status or family-structure variables. It should be noted, however, that the Bradley–Caldwell study is correlational. It therefore cannot be interpreted as indicating causality. Furthermore, their study pertained to preschool children. Children's IQ scores do not begin to predict adult IQ scores well until the age of 4. Moreover, before the age of 7, the scores are not stable (Bloom, 1964). Other work has suggested that factors such as maternal social support and interactive behavior may play a key role in the instability of scores on tests of intellectual ability between the ages of 2 and 8 (Pianta & Egeland, 1994).

The Bradley and Caldwell data should not be taken to indicate that demographic variables have little effect on IQ scores. On the contrary, throughout history and across cultures, many groups of people have been assigned pariah status as inferior members of the social order. Across cultures, these disadvantaged groups (e.g., native Maoris versus European New Zealanders) have shown differences in tests of intelligence and aptitude (Steele, 1990; Zeidner, 1990). Such was the case of the Burakumin tanners in Japan. In 1871, they were granted emancipation but not full acceptance into Japanese society. On the one hand, they show poor performance and underprivileged status in Japan. On the other hand, those who immigrate to America—and are treated like other Japanese immigrants—perform on IQ tests and in school achievement at a level comparable to that of their fellow Japanese Americans (Ogbu, 1986).

Similar positive effects of integration were shown on the other side of the world. In Israel, the children of European Jews score much higher on IQ tests than do children of Arabic Jews. The exception is when the children are reared on kibbutzim. Here, the children of all national ancestries are raised by specially trained caregivers, in a dwelling separate from their parents. When these children shared the same child-rearing environments, there were no national-ancestry–related differences in IQ (Smilansky, 1974).

Blackwell, Trzesniewski, and Dweck (2007) examined junior high school students and their beliefs about the nature of intelligence. The belief that intelligence is malleable predicted an improvement in mathematics achievement over the following 2 years. However, the students who believed that intelligence is fixed showed no significant change over this same time frame. In a second study, students whose math grades were declining were taught about the malleability of intelligence. The grades of students who received this training stopped declining. Furthermore, the students became more motivated in the classroom. However, the students who did not receive this training continued to show declines in their grades. These findings indicate that intelligence not only is malleable but also is greatly affected by our expectations.

Development of Intelligence in Adults

Intelligence develops with age (Anderson, 2005). Do scores on cognitive-ability tests continue to increase indefinitely? The available data suggest that they may not (Berg, 2000). Although crystallized intelligence is higher, on average, for older adults than for younger adults, fluid intelligence is higher, on average, for younger adults than for older ones (Horn & Cattell, 1966). At the college level, then, both fluid and crystallized abilities are increasing. Later in life, however, the picture often changes.

For example, the performance of older adults on many information-processing tasks appears to be slower, particularly on complex tasks (Cerella, 1990, 1991; Hertzog, 2011; Schaie, 1989). In general, crystallized cognitive abilities seem to increase throughout the life span, whereas fluid cognitive abilities seem to increase up until the 20s, 30s, or possibly 40s and slowly decrease thereafter. The preservation of crystallized abilities suggests that long-term memory and the structure and organization of knowledge representation are preserved across the life span (Salthouse, 2005, 2009). Moreover, many adults find ways of compensating for later deficits in skills so that their actual performance is unaffected. For example, older typists may type less quickly but look further ahead in their typing to compensate for the loss of processing speed (Salthouse, 1996). Or if they are forgetful, they may write notes to themselves more often than they did when they were younger.

Although psychometric researchers disagree about the age when fluid intelligence starts to decline, many researchers agree that eventually some decline does indeed occur, on average. The rate and extent of decline varies widely across people. Some cognitive abilities also seem to decline under some circumstances but not others, on average. For example, effectiveness of performance on some problem-solving tasks appears to show age-related decline (Denny, 1980; Hertzog, 2011), although even brief training appears to improve scores on problem-solving tasks for older adults (Rosenzweig & Bennett, 1996; Willis, 1985). Other research implicates declines in executive functioning as a reason for decreased performance on intelligence tests (Taconnat et al., 2007).

Not all cognitive abilities decline, however. For example, one book (Cerella et al., 1993) devotes 20 chapters to describing studies showing little or no intellectual decline in various areas of cognition, including object and word perception, language comprehension, and problem solving. Some researchers have found that some kinds of learning abilities seem to increase (e.g., Schaie & Willis, 1986), and others have found that the ability to learn and remember meaningful skills and information shows little decline (Graf, 1990; Labouvie-Vief & Schell, 1982; Perlmutter, 1983b). Also, even in a single domain, such as memory, decreases in one kind of performance may not imply decreases in another. For example, although short-term memory performance seems to decline (Hertzog, 2011; Hultsch & Dixon, 1990), long-term memory (Bahrick, Bahrick, & Wittlinger, 1975) and recognition memory (Schonfield & Robertson, 1966) remain quite good.

Some researchers (e.g., Schaie, 1996, 2005, 2009) even question much of the evidence for intellectual decline. For one thing, our views of memory and aging may be confounded by reports of pathological changes that occur in some older adults. Such changes do not result from general intellectual decline but rather from specific neurophysiological disorders. These neurophysiological disorders, such as Alzheimer's disease, are fairly uncommon even among the most elderly. Preventive screening tools for Alzheimer's disease, which capitalize on differences in typical aging adult abilities, currently are being investigated with mixed success (Mirmiran, von Someren, & Swaab, 1996). Cognitive abilities seem to decline most in the last 10 years before death. The amount of decline occurring in these later years is, in part, predicted by intelligence test scores early in life (Bourne et al., 2007).

Another qualification on findings of decline in older age is the frequent use of cross-sectional research designs, which involve testing different cohorts (generations) of individuals at the same time. Such designs tend to overestimate the extent of decline of cognitive abilities. For unknown reasons, more recent generations of individuals show higher cognitive abilities—at least as measured by IQ (Flynn, 1984, 1987, 2015)—than do earlier generations. Consequently, the lower IQs of the older individuals may be a generational effect rather than an aging effect. Indeed, longitudinal research designs, which test the same individuals repeatedly over an extended period, suggest less decline in mental abilities with age. These studies, however, may underestimate the extent of decline resulting from selective dropout. The less-able participants drop out of the study over the years, perhaps because they find the taking of the cognitive tests to be discouraging or even humiliating.

Although the debate about intellectual decline with age continues, positions have converged somewhat. For instance, there is a consensus (Cerella, 1990, 1991; Hertzog, 2011; Kliegl, Mayr, & Krampe, 1994; Salthouse, 1996) that some slowing of the rate of cognitive processing occurs across the span of adulthood, and the evidence of slowing remains even when the experimental methodology and analyses rule out the disproportionate representation of demented adults among the elderly (Salthouse, Kausler, & Saults, 1990). Among the general factors that have been suggested as contributing to age-related slowing of cognitive processing have been a generalized decline in central nervous system functioning (Cerella, 1991), a decline in working-memory capacity (Salthouse, 1993, 2009), a decline in attentional resources (see Horn & Hofer, 1992), and a decline in the functioning of the frontal lobes (Bugg et al., 2006).

Slowed processing might lead to cognitive deficits through two speed-related issues in cognitive functioning—limited time and simultaneity (Salthouse, 1996, 2009). Slowed processing may prevent certain operations from being computed. Such operations may need to occur within a limited amount of time. The operations may need to overlap because of storage limitations. For example, auditory memory exhibits rapid decay, leading to the necessity for rapid classification of auditory signals. Slowing of upper-level processing can result in incomplete or inaccurate processing of auditory signals. Given the semiparallel nature of much of cognitive processing along with the nature of synaptic transmission, that speed would be an issue is not surprising—such processing is time dependent.

In addition to these general factors, many cognitive-developmental psychologists have suggested that specific factors also affect age-related changes in cognitive processing. The specific factors differentially may affect various cognitive tasks. For example, specific factors include greater slowing of higher-order cognitive processes than of sensory-motor processes (Cerella, 1985). They also include differential slowing of high- versus low-complexity tasks (Kliegl, Mayr, & Krampe, 1994). A further cognitive factor is greater slowing for tasks requiring coordinative complexity (requiring simultaneous processing of multiple stimuli) than for sequential complexity (requiring sequential processing of multiple stimuli; Mayr & Kliegl, 1993). A final factor is greater age-related decline in processes of information retrieval than in processes of encoding (see Salthouse, 1992). In addition, priming effects and tasks requiring implicit memory seem to show little or no evidence of decline (Mitchell & Bruss, 2003). But tasks involving explicit memory do show age-related decline.

Older adults develop practical strategies to retain relatively high levels of functioning (Berg et al., 1998; Berg, Meegan, & Deviney, 1998; Hertzog, 2009; Sternberg, Grigorenko, & Oh, 2001). They also can draw on practical knowledge that younger people may not have (Berg, 2000; Colonia-Willner, 1998; Torff & Sternberg, 2001).

Although the evidence regarding age-related differences in the selection of cognitive strategies is mixed, there appear to be no age-related differences in self-monitoring of cognitive processes (see Salthouse, 1992). So it would appear that older adults may be able to effectively utilize information regarding how to enhance their cognitive performance. Also, when task performance is based more on accuracy than on speed, older adults may at least partly compensate for speed deficits with increased carefulness and persistence (see Horn & Hofer, 1992). Furthermore, at all times throughout the life span, there is considerable *plasticity*—modifiability—of abilities (Baltes, 1997; Baltes & Willis, 1979; Garlick, 2002; Mirmiran, von Someren, & Swaab, 1996; Rosenzweig & Bennett, 1996). None of us is stuck at a particular level of performance. Each of us can improve.

Some psychologists have become particularly interested in the development of wisdom in adulthood (see Sternberg, 1990; Sternberg & Jordan, 2005). Most theorists have argued that wisdom increases with age, although there are exceptions (Meacham, 1990). Psychologists' definitions of wisdom have been diverse. Some (Baltes et al., 1995; Baltes & Smith, 1990; Baltes & Staudinger, 2000; Staudinger & Glueck, 2011) define *wisdom* as exceptional insight into human development and life matters, including exceptionally good judgment and advice and commentary about difficult life problems. Furthermore, wisdom can be seen as reflecting a positive gain in culture-based cognitive pragmatics (meaningful uses of cognitive skills) in the face of the more physiologically controlled losses in cognitive mechanics (Baltes, 1993). Other research has found six factors in people's conceptions of wisdom. They are reasoning ability, sagacity (shrewdness), learning from ideas and from the environment, judgment, expeditious use of information, and perspicacity (intensely keen awareness, perception, and insight) (Sternberg, 1985b). In wisdom, to know what you do not know is also important (Meacham, 1983, 1990). Sternberg (2013) has characterized wisdom as involving the use of one's knowledge and abilities to help attain a common good, over the long term as well as the short term, through the infusion of positive ethical values. Whatever the definition of wisdom, it is clear that wisdom can help people adapt to their environments and make the world better not just for themselves but for others as well.

Artificial Intelligence: Computer Simulations

Can a Computer Program Be "Intelligent"?

Much of the early information-processing research centered on work based on computer simulations of human intelligence as well as computer systems that use optimal methods to solve tasks. Programs of both kinds can be classified as examples of *artificial intelligence* (AI), or intelligence in symbol-processing systems such as computers (see Schank & Towle, 2000). Computers cannot actually think. They must be programmed to behave as though they are thinking. That is, they must be programmed to simulate cognitive processes. In this way, they give us insight into the details of how people process information cognitively. Essentially, computers are just pieces of hardware—physical components of equipment—that respond to instructions. Other kinds of hardware (other pieces of equipment) also respond to instructions. For example, if you can figure out how to give the instructions, a DVR (digital video recorder) will respond to your instructions and will do what you tell it to do.

What makes computers so interesting to researchers is that they can be given highly complex instructions, known as computer programs or even more commonly as software. Programs tell the computer how to respond to new information.

Before we consider any intelligent programs, we need to consider seriously the issue of what, if anything, would lead us to describe a computer program as being "intelligent."

The Turing Test

Alan Turing (1963) probably made the first attempt to determine whether a computer program can be intelligent, based on ideas he first presented in 1950. Specifically, Turing devised a test by which a human could assess the intelligence of a respondent (see Chapter 1). The basic idea behind the Turing Test is whether an observer can distinguish the performance of a computer from that of a human. For the test to work, everyone must agree that the human is intelligent in at least some degree. In the specific form proposed by Turing, the test is conducted with a computer, a human respondent, and an interrogator. The interrogator has two different "conversations" with an interactive computer program. The goal of the interrogator is to figure out which of two parties is a person communicating through the computer and which is the computer itself. The interrogator can ask the two parties any questions at all. The computer, however, will try to fool the interrogator into believing that it is human. The human, in contrast, will try to show the interrogator that he or she truly is human. The computer passes the Turing Test if an interrogator is unable to distinguish the computer from the human.

The test of indistinguishability of computer from human is commonly used in assessing the intelligence of a computer program. The test is not usually performed in quite the way described by Turing. For example, outputs of some kind generated by a computer might be scanned and assessed for their comparability to human performance. In some cases, human data from a problem-solving task are compared with computer-generated data. The degree of relation between them is then evaluated. For example, suppose a computer solves number-series problems such as 1, 4, 9, 16, . . . (where each number is the next larger perfect square). The response times and error patterns of the computer can be compared with those of human participants who have solved the same problems (Kotovsky & Simon, 1973; Simon & Kotovsky, 1963). Of course, the response times of the computer are typically much faster than those of humans, but the researchers are less interested in overall reaction times than in patterns of reaction times. In other words, what matters is not whether computers take more or less time on each problem than do humans. Rather, it is whether the problems that take the computer relatively longer to solve also take human participants relatively longer.

Sometimes, the goal of a computer model is not to match human performance but to exceed it. In this case, maximum AI, rather than simulation of human intelligence, is the goal of the program. The criterion of whether computer performance matches that of humans is no longer relevant. Instead, the criterion of interest is that of how well the computer can perform the task assigned to it. Computer programs that play chess, for example, typically play in a way that emphasizes "brute force." The programs evaluate extremely large numbers of possible moves. Many of them are moves humans would never even consider evaluating (Berliner, 1969; Bernstein, 1958). Using brute force, the IBM program "Deep Blue" beat world champion Gary Kasparov in a 1997 chess match. The same brute-force method is used in programs that play checkers (Samuel, 1963). These programs generally are evaluated in terms of how well they can beat each other or, even more important, human contenders playing against them.

Applications of Artificial Intelligence

An application of AI can be seen in a competition sponsored by the Defense Advanced Research Projects Agency (DARPA). The program, originally called the DARPA Grand Challenge, requires groups to develop an automated vehicle (DARPA, 2007). Early versions of this project have had some success and have led to more challenging versions each year that it had been conducted. The most recent version of this challenge is the DARPA Urban Challenge, which requires the vehicle to independently perform in an urban environment including traffic (DARPA, 2007). This challenge does not permit drivers or control via a remote. As a result, these vehicles must integrate AI capable of assessing and reacting to new environments.

Another application of AI can be seen in the Mars rovers. The designers integrate AI into these rovers, enabling them to make (some) mission decisions and be self-reliant (Bluck, 2004). The application of AI to these projects has led to independent machines capable of performing complex operations in variable environments. Clearly, these applications are major improvements over the original attempts at AI.

Intelligence versus the Appearance of Intelligence

A philosopher has raised an objection to the basic idea that computers can be considered truly intelligent (Searle, 1980). To make his objection, he uses what is known as the "Chinese Room" problem. Imagine that Searle, the philosopher, is locked in a room. He is given a large batch of Chinese writing to translate. He knows no Chinese at all. Suppose that, in addition to the Chinese writing, Searle is given a second batch of Chinese script. He also receives a set of rules for translating the Chinese into English. Next, Searle is given a third batch. It gives him a set of rules for formulating responses to questions that were raised in the first batch of Chinese writing. Searle then responds to the original batch of writing with a response that makes sense and is in perfect Chinese. Presumably, over time, Searle could become extremely good at manipulating the rules. His responses would be every bit as good as those of a native Chinese speaker who understood exactly

practical applications of COGNITIVE PSYCHOLOGY

Cognitive Styles

What is your dominant cognitive style? Defining your preferred way of interacting with the environment could help you perform better in school or on the job. The "Thinking about Thinking" section at the end of each of the chapters in this text was designed to appeal to different cognitive styles to more meaningfully integrate the information in each chapter. Which questions were more appealing to you or helped you most? Analytical questions asked you to compare, analyze, or evaluate ideas; creative questions asked you to design or create; and practical questions asked you to apply information to other situations. Try to apply your knowledge in all three ways for the most effective and flexible use.

what was being asked. In fact, however, Searle still knows no Chinese at all. He is simply following a set of rules.

According to Searle, programs that seem to understand various kinds of inputs and to respond in a seemingly intelligent way are like Searle in the Chinese room. The computers understand the input being given to them no better than Searle understands Chinese. They are simply operating according to a set of preprogrammed rules. Searle's notion is that the computer does not really see and understand the connections between input and output. Rather, it uses preestablished connections that make it seem intelligent on the surface. To Searle, these programs do not demonstrate AI. They only appear to show intelligence.

Predictably, AI researchers have not competed with each other to be the first to accept Searle's argument. They generally have not been eager to acknowledge any folly in their attempts to model AI. A number of researchers have offered responses to Searle's charge that the computer is not anything like what it is cracked up to be. One scientist, for example, argued that Searle's use of the rule systems in the second and third batches of input is, in fact, intelligent (Abelson, 1980). He further argued that children learning a language also at first apply rules rather blindly. Only later do they come to understand the rules and how they are being used. Others argue that the system as a whole (comprising Searle as well as the set of instructions) does indeed exhibit understanding. In addition, some computer programs even have shown an ability to simulate at least a modest degree of skill development and knowledge acquisition. Nevertheless, existing computer programs do not begin to approach our human ability to enhance our own intelligence.

Key Themes

This chapter addresses several of the themes described in Chapter 1.

Nature versus nurture. This theme has played a major part in intelligence research since the 19th century. Investigators are in general agreement that nature plays a role. Intelligence is partially heritable. The estimates of heritability actually increase with age. The older you are, the more nature plays a role and the less nurture plays a role. This may be because of differential effects of early rearing environments that start to wear off. But the kind of environment an individual has affects the extent to which people can utilize and make the most of their genetic potential. Moreover, research shows that environment can affect biology. The brain changes as a result of learning experiences.