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Wisdom, Intelligence, and Creativity *Synthesized*

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Background Work on Intelligence

In the year 2000, Al Gore ran against George W. Bush for the presidency of the United States. Both candidates had highly successful political careers, Gore as a U.S. senator from the state of Tennessee and as vice-president of the United States, Bush as governor of the state of Texas, certainly one of the most complex states in the United States. Their success in politics was not preceded by success in school (Simon, 2000). Both men were mediocre students in college. In four years at Yale University, Bush never received an A, and Gore's grades at Harvard were even lower than Bush's at Yale. During his sophomore year, Gore received one B, two Cs, and a D (on a scale where A is high and D is the lowest passing grade). Their college admission test scores were also undistinguished. Gore received a 625 on the verbal SAT (on a scale where 200 is low, 500 average, and 800 high, and where the standard deviation is 100 points). Bush received a score of 566. Bill Bradley, a former U.S. senator and a Democratic presidential primary candidate, received an even less impressive score of 485.

Are these famous politicians unintelligent, intelligent in some way not measured by conventional tests, or what? What does it mean to be intelligent, anyway, and how does our understanding of the nature of intelligence help us understand concrete cases such as Bradley, Bush, and Gore?

CONCEPTIONS OF THE NATURE OF INTELLIGENCE

Anyone who has seriously studied the history of the United States or of any other country knows that there is not one history of a country but many histories. The history of the United States as told by some American Indians, for example, would look quite different from the history as told by some of the later settlers, and even within these groups, the stories would differ. Similarly, there is no one history of the field of intelligence, but

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rather, many histories, depending on who is doing the telling. For example, the largely laudatory histories recounted by Carroll (1982, 1993), Herrnstein and Murray (1994), and Jensen (1998, 2002) read very differently from the largely skeptical histories recounted by Gardner (1983, 1999), Gould (1981) or Sacks (1999). And there are differences within these groups of authors.

These differences need mentioning because, although all fields of psychology are perceived through ideological lenses, few fields seem to have lenses with so many colors and, some might argue, with so many different distorting imperfections as do the lenses through which are seen the field of intelligence. The different views come not only from ideological biases affecting what is said, but also from affecting what is included. For example, there is virtually no overlap in the historical data used by Carroll (1993) and those used by Gardner (1983) to support their respective theories of intelligence.

Although no account can be truly value-free, I try in this chapter to clarify values in three ways. First, I attempt to represent the views of the investigators and their times in presenting the history of the field. Second, I critique this past work, but make my own personal opinions clear by labeling evaluative sections "Evaluation." Third, I try to represent multiple points of view in a dialectical fashion (Hegel, 1807/1931; see Sternberg, 1999a), pointing out both the positive and negative sides of various contributions. This representation recognizes that all points of view taken in the past can be viewed, with "20/20 hindsight," as skewed, in much the same way that present points of view will be viewed as skewed in the future. A dialectical form of examination will serve as the basis for the entire chapter. The basic idea is that important ideas, good or bad, eventually serve as the springboard for other new ideas that grow out of unions of past ideas that may once have seemed incompatible.

The emphasis in this chapter is on the background history of the field of intelligence, particularly with reference to theories of intelligence. Readers interested primarily in measurement issues might consult relevant chapters in Sternberg (1982, 1994b, 2000b).

Perhaps the most fundamental dialectic in the field of intelligence arises from the question of how we should conceive of intelligence. Several different positions have been staked out (Sternberg, 1990a). Many of the differences in ideology that arise in accounts of the history of the field of intelligence arise from differences in the model of intelligence to which an investigator adheres. To understand the history of the field of intelligence, one must understand the alternative epistemological models that can give rise to the concept of intelligence. But before addressing these models, consider simply the question of how psychologists in the field of intelligence have defined the construct on which they base their models.

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Expert Opinions on the Nature of Intelligence

Historically, one of the most important approaches to figuring out what intelligence is has relied on the opinions of experts. Such opinions are sometimes referred to as *implicit theories*, to distinguish them from the more formal *explicit theories* that serve as the bases for scientific hypotheses and subsequent data collections.

Implicit theories (which can be those of laypersons as well as experts) are important to the history of a field for at least three reasons (Sternberg, Conway, Ketron, & Bernstein, 1981). First, experts' implicit theories are typically what give rise to their explicit theories. Second, much of the history of intelligence research and practice is much more closely based on implicit theories than it is on formal theories. Most of the intelligence tests that have been used, for example, are based more on the opinions of their creators as to what intelligence is than on formal theories. Third, people's everyday judgments of each other's intelligence always have been and continue to be much more strongly guided by their implicit theories of intelligence than by any explicit theories.

Intelligence Operationally Defined. E. G. Boring (1923), in an article in the *New Republic*, proposed that intelligence is what the tests of intelligence test. Boring did not believe that this operational definition was the end of the line for understanding intelligence. On the contrary, he saw it as a "narrow definition, but a point of departure for a rigorous discussion . . . until further scientific discussion allows us to extend [it]" (p. 35). Nevertheless, many psychologists and especially testers and interpreters of tests of intelligence have adopted this definition or something similar to it.

From a scientific point of view, the definition is problematic. First, the definition is circular: It defines intelligence in terms of what intelligence tests test, but what the tests test can only be determined by one's definition of intelligence. Second, the definition legitimates rather than calling into scientific question whatever operations are in use at a given time to measure intelligence. To the extent that the goal of science is to disconfirm existing scientific views (Popper, 1959), such a definition will not be useful. Third, the definition assumes that what intelligence tests test is uniform. But this is not the case. Although tests of intelligence tend to correlate positively with each other (the so-called *positive manifold* first noted by Spearman, 1904), such correlations are far from perfect, even controlling for unreliability. Thus, what intelligence tests test is not just one uniform thing. Moreover, even the most ardent proponents of a general factor of intelligence (a single element common to all of these tests) acknowledge there is more to intelligence than just the general factor.

The 1921 Symposium. Probably the best-known study of experts' definitions of intelligence was one done by the editors of the *Journal of Educational*

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Psychology ("Intelligence and its measurement," 1921). Contributors to the symposium were asked to address two issues: (a) what they conceived intelligence to be and how it best could be measured by group tests, and (b) what the most crucial next steps would be in research. Fourteen experts gave their views on the nature of intelligence, with such definitions as the following:

1. the power of good responses from the point of view of truth or facts (E. L. Thorndike)
2. the ability to carry on abstract thinking (L. M. Terman)
3. sensory capacity, capacity for perceptual recognition, quickness, range or flexibility of association, facility and imagination, span of attention, quickness or alertness in response (F. N. Freeman)
4. having learned or ability to learn to adjust oneself to the environment (S. S. Colvin)
5. ability to adapt oneself adequately to relatively new situations in life (R. Pintner)
6. the capacity for knowledge and knowledge possessed (B. A. C. Henmon)
7. a biological mechanism by which the effects of a complexity of stimuli are brought together and given a somewhat unified effect in behavior (J. Peterson)
8. the capacity to inhibit an instinctive adjustment, the capacity to redefine the inhibited instinctive adjustment in the light of imaginally experienced trial and error, and the capacity to realize the modified instinctive adjustment in overt behavior to the advantage of the individual as a social animal (L. L. Thurstone)
9. the capacity to acquire capacity (H. Woodrow)
10. the capacity to learn or to profit by experience (W. F. Dearborn)
11. sensation, perception, association, memory, imagination, discrimination, judgment, and reasoning (N. E. Haggerty)

Others of the contributors to the symposium did not provide clear definitions of intelligence but rather concentrated on how to test it. B. Ruml refused to present a definition of intelligence, arguing that not enough was known about the concept. S. L. Pressey described himself as uninterested in the question, although he became well known for his tests of intelligence.

There have been many definitions of intelligence since those presented in the *Journal* symposium, and an essay has been written on the nature of definitions of intelligence (Miles, 1957). One well-known set of definitions was published in 1986 as an explicit follow-up to the 1921 symposium (Sternberg & Detterman, 1986).

Sternberg and Berg (1986) attempted a comparison of the views of experts (P. Baltes, J. Baron, J. Berry, A. Brown & J. Campione, E. Butterfield, J. Carroll, J. P. Das, D. Detterman, W. Estes, H. Eysenck, H. Gardner,

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R. Glaser, J. Goodnow, J. Horn, L. Humphreys, E. Hunt, A. Jensen, J. Pellegrino, R. Schank, R. Snow, R. Sternberg, E. Zigler) with those of the experts in 1921. They reached three general conclusions.

First, there was at least some general agreement across the two symposia regarding the nature of intelligence. When attributes were listed for frequency of mention in the two symposia, the correlation was .50, indicating moderate overlap. Attributes such as adaptation to the environment, basic mental processes, higher order thinking (e.g., reasoning, problem solving, and decision making) were prominent in both symposia.

Second, central themes occurred in both symposia. One theme was the one versus the many: Is intelligence one thing or is it multiple things? How broadly should intelligence be defined? What should be the respective roles of biological versus behavioral attributes in seeking an understanding of intelligence?

Third, despite the similarities in views over the sixty-five years, some salient differences could also be found. Metacognition – conceived of as both knowledge about and control of cognition – played a prominent role in the 1986 symposium but virtually no role at all in 1921. The later symposium also placed a greater emphasis on the role of knowledge and the interaction of mental processes with this knowledge.

Lay Conceptions of Intelligence

In some cases, Western notions about intelligence are not shared by other cultures. For example, the Western emphasis on speed of mental processing (Sternberg, Conway, Ketron, & Bernstein, 1981) is not shared by many cultures. Other cultures may even be suspicious of the quality of work that is done very quickly. They emphasize depth rather than speed of processing. They are not alone: Some prominent Western theorists have pointed out the importance of depth of processing for full command of material (e.g., Craik & Lockhart, 1972).

Yang and Sternberg (1997a) have reviewed Chinese philosophical conceptions of intelligence. The Confucian perspective emphasizes the characteristic of benevolence and of doing what is right. As in the Western notion, the intelligent person spends a great deal of effort in learning, enjoys learning, and persists in lifelong learning with a great deal of enthusiasm. The Taoist tradition, in contrast, emphasizes the importance of humility, freedom from conventional standards of judgment, and full knowledge of oneself as well as of external conditions.

The differences between Eastern and Western conceptions of intelligence have extended beyond ancient times and persist even in the present day. Yang and Sternberg (1997b) studied contemporary Taiwanese Chinese conceptions of intelligence, and found five factors underlying these conceptions: (a) a general cognitive factor, much like the *g* factor in conventional

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(initiative), with only the first directly referring to knowledge-based skills (including but not limited to the academic).

It is important to recognize that there is no one overall U.S. conception of intelligence. Indeed, Okagaki and Sternberg (1993) found that different ethnic groups in San Jose, California, had rather different conceptions of what it means to be intelligent. Latino parents of schoolchildren tended to emphasize the importance of social-competence skills in their conceptions, whereas Asian parents tended rather heavily to emphasize the importance of cognitive skills. Anglo parents also emphasized cognitive skills. Teachers, representing the dominant culture, more emphasized cognitive than social-competence skills. The rank order of performance among children of various groups (including subgroups within the Latino and Asian groups) could be perfectly predicted by the extent to which their parents shared the teachers' conceptions of intelligence. Teachers tended to reward those children who were socialized into a view of intelligence that happened to correspond to their own. Yet, as we shall argue later, social aspects of intelligence, broadly defined, may be as important as, or even more important than, cognitive aspects of intelligence in later life. Some, however, prefer to study intelligence not in its social aspect, but in its cognitive one.

Definitions of any kind can provide a basis for explicit scientific theory and research, but they do not provide a substitute for them. Thus it was necessary for researchers to move beyond definitions, which they indeed did. Many of them moved to models based on individual differences.

Intelligence as Arising from Individual Differences: The Differential Model

McNemar (1964) was one of the most explicit in speculating on why we even have a concept of intelligence and in linking the rationale for the concept to individual differences. He queried whether identical twins stranded on a desert island and growing up together would ever generate the notion of intelligence if they never encountered individual differences in their mental abilities.

Perhaps without individual differences, societies would never generate the notion of intelligence and languages would contain no corresponding term. Actually, some languages, such as Mandarin Chinese, have no concept that corresponds precisely to the Western notion of intelligence (Yang & Sternberg, 1997a, 1997b), although they have related concepts that are closer, say, to the Western notion of wisdom or other constructs. Whatever may be the case, much of the history of the field of intelligence is based on an epistemological model deriving from the existence of one or more kinds of individual differences.

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THE SEMINAL VIEWS OF GALTON AND BINET

If current thinking about the nature of intelligence owes a debt to any scholars it is to Sir Francis Galton and Alfred Binet. These two investigators – Galton at the end of the nineteenth century and Binet at the beginning of the twentieth century – have had a profound impact on thinking about intelligence, an impact felt to this day. Many present conflicting views regarding the nature of intelligence can be traced to a dialectical conflict between Galton and Binet.

Intelligence is Simple: Galton's Theory of Psychophysical Processes

Intelligence as Energy and Sensitivity. The publication of Darwin's (1859) *Origin of Species* had a profound impact on many lines of scientific endeavor. One of these lines of endeavor was the investigation of human intelligence. The book suggested that the capabilities of humans were in some sense continuous with those of lower animals, and hence could be understood through scientific investigation.

Galton (1883) followed up on these notions to propose a theory of the "human faculty and its development." Because Galton also proposed techniques for measuring the "human faculty," his theory could be applied directly to human behavior.

Galton proposed two general qualities that he believed distinguish the more from the less intellectually able. His epistemological rooting, therefore, was in the individual-differences approach. The first quality was *energy*, or the capacity for labor. Galton believed that intellectually gifted individuals in a variety of fields are characterized by remarkable levels of energy. The second general quality was *sensitivity*. Galton observed that the only information that can reach us concerning external events passes through the senses and that the more perceptive the senses are of differences in luminescence, pitch, odor, or whatever, the larger would be the range of information on which intelligence could act. Galton's manner of expression was direct:

> The discriminative facility of idiots is curiously low; they hardly distinguish between heat and cold, and their sense of pain is so obtuse that some of the more idiotic seem hardly to know what it is. In their dull lives, such pain as can be excited in them may literally be accepted with a welcome surprise. (p. 28)

For seven years (1884–1890), Galton maintained an anthropometric laboratory at the South Kensington Museum in London where, for a small fee, visitors could have themselves measured on a variety of psychophysical tests. What, exactly, were these tests?

One was for weight discrimination. The apparatus consisted of cases of shot, wool, and wadding. The cases were identical in appearance and

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differed only in their weight. Participants were tested by a sequencing task. They were given three cases and, with their eyes closed, had to arrange them in proper order of weight. The weights formed a geometric series of heaviness, and the examiner recorded the finest interval that an examinee could discriminate. Galton suggested that similar geometric sequences could be used for testing other senses, such as touch and taste. With touch, Galton proposed the use of wirework of various degrees of fineness, whereas for taste he proposed the use of stock bottles of solutions of salt of various strengths. For olfaction, he suggested the use of bottles of attar of rose mixed in various degrees of dilution.

Galton also contrived a whistle for ascertaining the highest pitch that different individuals could perceive. Tests with the whistle enabled him to discover that people's ability to hear high notes declines considerably as age advances. He also discovered that people are inferior to cats in their ability to perceive tones of high pitch.

It is ironic, perhaps, that a theory that took off from Darwin's theory of evolution ended up in what some might perceive as a predicament, at least for those who believe that evolutionary advance is, in part, a matter of complexity (Kauffman, 1995). In most respects, humans are evolutionarily more complex than cats. Galton's theory, however, would place cats, who are able to hear notes of higher pitch than humans, at a superior level to humans at least with respect to this particular aspect of what Galton alleged to be intelligence.

Cattell's Operationalization of Galton's Theory. James McKeen Cattell brought many of Galton's ideas across the ocean to the United States. As head of the psychological laboratory at Columbia University, Cattell was in a good position to publicize the psychophysical approach to the theory and measurement of intelligence. J. M. Cattell (1890) proposed a series of fifty psychophysical tests. Four examples were

1. *Dynamometer pressure.* The dynamometer-pressure test measures the pressure resulting from the greatest possible squeeze of one's hand.
2. *Sensation areas.* This test measures the distance on the skin by which two points must be separated in order for them to be felt as separate points. Cattell suggested that the back of the closed right hand between the first and second fingers be used as the basis for measurement.
3. *Least noticeable difference in weight.* This test measures the least noticeable differences in weights by having participants judge weights of small wooden boxes. Participants were handed two such boxes and asked to indicate which was heavier.
4. *Bisection of a 50-cm line.* In this test, participants were required to divide a strip of wood into two equal parts by means of a movable line.

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Wissler Blows the Whistle. A student of Cattell's, Clark Wissler (1901), decided to validate Cattell's tests. Using twenty-one of the tests, he investigated among Columbia University undergraduates the correlations of the tests with each other and with college grades. The results were devastating: Test scores neither intercorrelated much among themselves nor did they correlate significantly with undergraduate grades. The lack of correlation could not have been due entirely to unreliability of the grades or to restriction of range, because the grades did correlate among themselves. A new approach seemed to be needed.

Evaluation. Even those later theorists who were to build on Galton's work (e.g., Hunt, Frost, & Lunneborg, 1973) recognized that Galton was overly simplistic in his conception and measurement of intelligence. Galton was also pejorative toward groups whom he believed to be of inferior intelligence. Yet one could argue that Galton set at least three important precedents.

A first precedent was the desirability of precise quantitative measurement. Much of psychological measurement, particularly in the clinical areas, has been more qualitative, or based on dubious rules about translations of qualitative responses to quantitative measurements. Galton's psychometric precision set a different course for research and practice in the field of intelligence. His combination of theory and measurement techniques set a precedent: Many future investigators would tie their theories, strong or weak, to operations that would enable them to measure the intelligence of a variety of human populations.

A second precedent was the interface between theory and application. Galton's Kensington Museum enterprise set a certain kind of tone for the intelligence measurement of the future. No field of psychology, perhaps, has been more market-oriented than has been the measurement of intelligence. Testing of intelligence has been highly influenced by market demands, more so, say, than testing of memory abilities or social skills. It is difficult to study the history of the field of intelligence without considering both theory and practice.

A third precedent was a tendency to conflate scores on tests of intelligence with some kind of personal value. Galton made no attempt to hide his admiration for hereditary geniuses (Galton, 1869) nor to hide his contempt for those at the lower end of the intelligence scale as he perceived it (Galton, 1883). He believed those at the high end of the scale had much more to contribute than those at the low end. The same kinds of judgments do not pervade the literatures of, say, sensation or memory. This tendency to conflate intelligence with some kind of economic or social value to society and perhaps beyond society has continued to the present day (for example, Herrnstein & Murray, 1994; Schmidt & Hunter, 1998).

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Intelligence is Complex: Binet's Theory of Judgment

In 1904, the Minister of Public Instruction in Paris established a commission charged with studying or creating tests that would insure that mentally defective children (as they then were called) would receive an adequate education. The commission decided that no child suspected of retardation should be placed in a special class for children with mental retardation without first being given an examination, "from which it could be certified that because of the state of his intelligence, he was unable to profit, in an average measure, from the instruction given in the ordinary schools" (Binet & Simon, 1916a, p. 9).

Binet and Simon devised a test based on a conception of intelligence very different from Galton's and Cattell's. They viewed judgment as central to intelligence. At the same time, they viewed Galton's tests as ridiculous. They cited Helen Keller as an example of someone who was very intelligent but who would have performed terribly on Galton's tests.

Binet and Simon's (1916b) theory of intelligent thinking in many ways foreshadowed later research on the development of metacognition (for example, Brown & DeLoache, 1978; Flavell & Wellman, 1977; Nelson, 1999). According to Binet and Simon (1916a), intelligent thought comprises three distinct elements: direction, adaptation, and control.

Direction consists in knowing what has to be done and how it is to be accomplished. When we are required to add three numbers, for example, we give ourselves a series of instructions on how to proceed, and these instructions form the direction of thought.

Adaptation refers to one's selection and monitoring of one's strategy during task performance. For example, in adding two numbers, one first needs to decide on a strategy to add the numbers. As we add, we need to check (monitor) that we are not repeating the addition of any of the digits we already have added.

Control is the ability to criticize one's own thoughts and actions. This ability often occurs beneath the conscious level. If one notices that the sum one attains is smaller than either number (if the numbers are positive), one recognizes there is a mistake in one's addition and one must add the numbers again.

Binet and Simon (1916a) distinguished between two types of intelligence, ideational intelligence and instinctive intelligence. *Ideational intelligence* operates by means of words and ideas. It uses logical analysis and verbal reasoning. *Instinctive intelligence* operates by means of feeling. It refers not to the instincts attributed to animals and to simple forms of human behavior, but to lack of logical thinking. This two-process kind of model adumbrates many contemporary models of thinking (for example, Epstein, 1985; Evans, 1989; Sloman, 1996), which make similar distinctions.

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defined very clearly). Whatever it was, it was a unitary and primary source of individual differences in intelligence test performance.

The Theories of Bonds and of Connections

Theory of Bonds. Spearman's theory was soon challenged, and continues to be challenged today (for example, Gardner, 1983; Sternberg, 1999d). One of Spearman's chief critics was British psychologist Sir Godfrey Thomson, who accepted Spearman's statistics but not his interpretation. Thomson (1939) argued that it is possible to have a general psychometric factor in the absence of any kind of general ability. In particular, he argued that *g* is a statistical reality but a psychological artifact. He suggested that the general factor might result from the working of an extremely large number of what he called *bonds*, all of which are sampled simultaneously in intellectual tasks. Imagine, for example, that each of the intellectual tasks found in the test batteries of Spearman and others requires certain mental skills. If each test samples all these mental skills, then their appearance will be perfectly correlated with each other because they always co-occur. Thus, they will give the appearance of a single general factor, when in fact they are multiple.

Although Thomson did not attempt to specify exactly what the bonds might be, it is not hard to speculate on what some of these common elements are. For example, they might include understanding the problems and responding to them.

Theory of Connections. Thorndike, Bregman, Cobb, and Woodyard (1926) proposed a quite similar theory, based on Thorndike's theory of learning. They suggested that

> in their deeper nature the higher forms of intellectual operations are identical with mere association or connection forming, depending on the same sort of physiological connections but requiring *many more of them*. By the same argument the person whose intellect is greater or higher or better than that of another person differs from him in the last analysis in having, not a new sort of physiological process, but simply a larger number of connections of the ordinary sort. (p. 415)

According to this theory, then, learned connections, similar to Thomson's bonds, are what underlie individual differences in intelligence.

Thurstone's Theory of Primary Mental Abilities

Louis L. Thurstone, like Spearman, was an ardent advocate of factor analysis as a method of revealing latent psychological structures underlying observable test performances. Thurstone (1938, 1947) believed, however, that it was a mistake to leave the axes of factorial solutions unrotated. He

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believed that the solution thus obtained was psychologically arbitrary. Instead, he suggested rotation to what he referred to as *simple structure*, which is designed to clean up the columns of a factor pattern matrix so that the factors display either relatively high or low loadings of tests on given factors, rather than large numbers of moderate ones. Using simple-structure rotation, Thurstone and Thurstone (1941) argued for the existence of seven primary mental abilities.

1. *Verbal comprehension:* the ability to understand verbal material. This ability is measured by tests such as vocabulary and reading comprehension.
2. *Verbal fluency:* the ability involved in rapidly producing words, sentences, and other verbal material. This ability is measured by tests such as one that requires the examinee to produce as many words as possible beginning with a certain letter in a short amount of time.
3. *Number:* the ability to compute rapidly. This ability is measured by tests requiring solution of numerical arithmetic problems and simple arithmetic word problems.
4. *Memory:* the ability to remember strings of words, letters, numbers, or other symbols or items. This ability is measured by serial- or free-recall tests.
5. *Perceptual speed:* the ability to recognize letters, numbers, or other symbols rapidly. This ability is measured by proofreading tests, or by tests that require individuals to cross out a given letter (such as *A*) in a string of letters.
6. *Inductive reasoning:* the ability to reason from the specific to the general. This ability is measured by tests such as letter series ("What letter comes next in the following series? b, d, g, k, ...") and number series ("What number comes next in the following series? 4, 12, 10, 30, 28, 84, . . .").
7. *Spatial visualization:* the ability involved in visualizing shapes, rotations of objects, and how pieces of a puzzle would fit together. This ability is measured by tests that require mental rotations or other manipulations of geometric objects.

The argument between Spearman and Thurstone could not be resolved on mathematical grounds, simply because in exploratory factor analysis, any of an infinite number of rotations of axes is acceptable. As an analogy, consider axes used to understand world geography (Vernon, 1971). One can use lines of longitude and latitude, but really, any axes at all could be used, orthogonal or oblique, or even axes that serve different functions, such as in polar coordinates. The locations of points, and the distances between them, do not change in Euclidean space as a result of how the axes are placed.

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Because Thurstone's primary mental abilities are intercorrelated, Spearman and others have argued that they are nothing more than varied manifestations of *g*: Factor analyze these factors, and a general factor will emerge as a second-order factor. Thurstone argued that the primary mental abilities were more basic. Such arguments became largely polemical because there neither was nor is any way of resolving the debate in the terms in which it was presented. Some synthesis was needed for the opposing thesis of *g* versus the antithesis of primary mental abilities.

Hierarchical Theories

The main synthesis to be proposed was to be hierarchical theories – theories that assume that abilities can be ordered in terms of levels of generality. Rather than arguing which abilities are more fundamental, hierarchical theorists have argued that all the abilities have a place in a hierarchy of abilities from the general to the specific.

Holzinger's Bifactor Theory. Holzinger (1938) proposed a bifactor theory of intelligence, which retained both the general and specific factors of Spearman, but also permitted group factors such as those found in Thurstone's theory. Such factors are common to more than one test, but not to all tests. This theory helped form the basis for other hierarchical theories that replaced it.

Burt's Theory. Sir Cyril Burt (1949), known primarily for his widely questioned work on the heritability of intelligence, suggested that a five-level hierarchy would capture the nature of intelligence. At the top of Burt's hierarchy was "the human mind." At the second level, the "relations level," are *g* and a practical factor. At the third level are associations, at the fourth level, perception, and at the fifth level, sensation. This model has proved not to be durable and is relatively infrequently cited today.

Vernon's Theory of Verbal : Educational and Spatial : Mechanical Abilities. A more widely adopted model has been that of Vernon (1971), which proposes the general factor, *g*, at the top of the hierarchy. Below this factor are two group factors, *v:ed* and *k:m*. The former refers to verbal-educational abilities of the kinds measured by conventional tests of scholastic abilities. The latter refers to spatial-mechanical abilities (with *k* perhaps inappropriately referring to the nonequivalent term *kinesthetic*).

Cattell's Theory of Fluid and Crystallized Abilities. More widely accepted than any of the above theories is that of Raymond Cattell (1971), which is somewhat similar to Vernon's theory. Cattell's theory proposes general ability at the top of the hierarchy and two abilities immediately

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beneath it, fluid ability, or g_f, and crystallized ability, or g_c. Fluid ability is the ability to think flexibly and to reason abstractly. It is measured by tests such as number series and figural analogies. Crystallized ability is the accumulated knowledge base one has developed over the course of one's life as the result of the application of fluid ability. It is measured by tests such as vocabulary and general information.

More recent work has suggested that fluid ability is extremely difficult to distinguish statistically from general ability (Gustafsson, 1984, 1988). The tests used to measure fluid ability are often identical to the tests used to measure what is supposed to be pure *g*. An example of such a test would be the Raven Progressive Matrices (Raven, 1986), which measures people's ability to fill in a missing part of a matrix comprising abstract figural drawings.

Horn (1994) has greatly expanded on the hierarchical theory as originally proposed by Cattell. Most notably, he has suggested that *g* can be split into three more factors nested under fluid and crystallized abilities. These three other factors are visual thinking (g_v), auditory thinking (g_a), and speed (g_s). The visual thinking factor is probably closer to Vernon's *k:m* factor than it is to the fluid ability factor.

Carroll's Three-Stratum Theory. Perhaps the most widely accepted hierarchical model today is that proposed by Carroll (1993), which is based on the reanalysis of (more than 450) data sets from the past. At the top of the hierarchy is general ability; in the middle of the hierarchy are various broad abilities, including fluid and crystallized intelligence, learning and memory processes, visual and auditory perception, facile production, and speed. At the bottom of the hierarchy are fairly specific abilities.

Guilford's Structure-of-Intellect Model. Although many differential theorists followed the option of proposing a hierarchical model, not all did. J. P. Guilford (1967, 1982; Guilford & Hoepfner, 1971) proposed a model with 120 distinct abilities (increased to 150 in 1982 and to 180 in later manifestations). The basic theory organizes abilities along three dimensions: operations, products, and contents. In the best known version of the model, there are five operations, six products, and four contents. The five operations are cognition, memory, divergent production, convergent production, and evaluation. The six products are units, classes, relations, systems, transformations, and implications. The four contents are figural, symbolic, semantic, and behavioral. Because these dimensions are completely crossed with each other, they yield a total of $5 \times 6 \times 4$ or 120 different abilities. For example, inferring a relation in a verbal analogy (such as the relation between BLACK and WHITE in BLACK : WHITE :: HIGH : LOW) would involve cognition of semantic relations.

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Guilford's model has not fared well psychometrically. Horn and Knapp (1973) showed that random theories could generate support equal to that obtained by Guilford's model when the same type of rotation was used that Guilford used – so-called "Procrustean rotation." Horn (1967) showed that equal support could be obtained with Guilford's theory, but with data generated randomly rather than with real data. These demonstrations do not prove the model wrong: They show only that the psychometric support that Guilford claimed for his model was not justified by the methods he used.

Guttman's Radex Model. The last psychometric model to be mentioned is one proposed by Louis Guttman (1954). The model is what Guttman referred to as a radex, or radial representation of complexity.

The radex consists of two parts. The first part Guttman calls a simplex. If one imagines a circle, then the simplex refers to the distance of a given point (ability) from the center of the circle. The closer a given ability is to the center of the circle, the more central that ability is to human intelligence. Thus, *g* could be viewed as being at the center of the circle, whereas the more peripheral abilities such as perceptual speed would be nearer to the periphery of the circle. Abilities nearer to the periphery of the circle are viewed as being constituents of abilities nearer the center of the circle, so the theory has a hierarchical element.

The second part of the radex is called the circumplex. It refers to the angular orientation of a given ability with respect to the circle. Thus, abilities are viewed as being arranged around the circle with abilities that are more highly related (correlated) nearer to each other in the circle. Thus, the radex functions through a system of polar coordinates. Snow, Kyllonen, and Marshalek (1984) used nonmetric multidimensional scaling on a Thurstonian type of test to demonstrate that the Thurstonian primary mental abilities actually could be mapped into a radex.

Evaluation

Psychometric theories of intelligence have been enormously influential, particularly in North America and in the United Kingdom. In many respects, they have served the field well. First, they have provided a Zeitgeist for three generations of researchers. Second, they have provided a systematic means for studying individual differences. Arguably, no other paradigm has provided a means nearly as systematic or successful in so many respects. Third, the theories cross well between theory and application. Few theories have proved to have as many and as diverse practical applications. Finally, they have provided a model for how theory and measurement can evolve in synchrony.

At the same time, there have been problems with the differential approach. First, although factor analysis, as a method, is neither good nor bad,

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appearance. Suppose, for example, a child is shown two glasses, one short and fat and the other tall and thin. If a preoperational child watches water poured from the short, fat glass to the tall, thin one, he or she will say that the tall, thin glass has more water than the short, fat one had. But the concrete–operational child will recognize that the quantity of water is the same in the new glass as in the old glass, despite the change in physical appearance.

The period of *formal operations* begins to evolve at around eleven years of age and usually will be fairly fully developed by sixteen years of age, although some adults never completely develop formal operations. In the period of formal operations, the child acquires the ability to think abstractly and hypothetically, not just concretely. The individual can view a problem from multiple points of view and think much more systematically than in the past. For example, if asked to provide all possible permutations of the numbers 1, 2, 3, and 4, the child can now implement a systematic strategy for listing all these permutations. In contrast, the concrete–operational child will have essentially listed permutations at random, without a systematic strategy. The child can now think scientifically and use the hypotheticodeductive method to generate and test hypotheses.

Vygotsky and Feuerstein's Theories. Whereas Piaget has emphasized primarily biological maturation in the development of intelligence, other theorists interested in structures, such as Vygotsky (1978) and Feuerstein (1979), have more emphasized the role of interactions of individuals with the environment. Vygotsky suggested that basic to intelligence is *internalization*, which is the internal reconstruction of an external operation. The basic notion is that we observe those in the social environment around us acting in certain ways and we internalize their actions so that they become a part of us.

Vygotsky (1978) gave an example of internalization in the development of pointing. He suggested that, initially, pointing is nothing more than an unsuccessful attempt to grasp something. The child attempts to grasp an object beyond his reach and fails. When the mother sees the child attempting to grasp the object, she comes to his aid and is likely to point to it. He thereby learns to do the same. Thus, the child's unsuccessful attempt engenders a reaction from the mother or some other individual, which leads to his being able to perform that action. Note that it is the social mediation, rather than the object itself, which provides the basis for the child's learning to point.

Vygotsky also proposed the important notion of a *zone of proximal development*, which refers to functions that have not yet matured but are in the process of maturation. The basic idea is to look not only at developed abilities, but also at abilities that are developing. This zone is often measured as the difference between performance before and after instruction. Thus,

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instruction is given at the time of testing to measure the individual's ability to learn in the testing environment (Brown & French, 1979; Feuerstein, 1980; Grigorenko & Sternberg, 1998). The research suggests that tests of the zone of proximal development tap abilities not measured by conventional tests.

Related ideas have been proposed by Feuerstein (1979, 1980). Feuerstein has suggested that much of intellectual development derives from the mediation of the environment by the mother or other adults. From Feuerstein's point of view, parents serve an important role in development not only for the experiences with which they provide children, but also for the way they help children understand these experiences. For example, what would be important would be not so much encouraging children to watch educational television or taking children to museums, but rather, helping them interpret what they see on television or in museums.

Evaluation

By any standard, Piaget's contribution to the study of intelligence was profound. First, his theory stands alone in terms of its comprehensiveness in accounting for intellectual development. There is no competition in this respect. Second, even the many individuals who have critiqued Piaget's work have honored it by deeming it worthy of criticism. To the extent that a theory's value is heuristic, in its giving way to subsequent theories, Piaget's work is almost without par. Much research today, especially in Europe, continues in the tradition of Piaget. Neo-Piagetians, although they have changed many of the details, still build on many Piagetian theoretical ideas and tasks for studying development. Third, even the most ardent critics of Piaget would concede that many of his ideas, such as of centration, conservation, and equilibration, were correct and remain alive today in a wide variety of forms. Fourth, Piaget provided an enormous database for developmental psychologists to deal with today. Replications generally have proven to be successful (Siegler, 1998).

Yet the theory of Piaget has not stood the test of time without many scars. Consider some of the main ones.

First, Piaget's interpretations of data have proven to be problematical in many different respects. The list of such critiques is very long. For example, there is evidence that infants achieve object permanence much earlier than Piaget had thought (for example, Baillargeon, 1987; Cornell, 1978). There is also evidence that conservation begins earlier than Piaget suspected (Au, Sidle, & Rollins, 1993). As another example, difficulties that Piaget attributed to reasoning appear in some instances actually to have been due to memory (e.g., Bryant & Trabasso, 1971).

Second, it now appears that children often failed Piagetian tasks not because they were unable to do them, but because they did not understand

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the task in the way the experimenter intended. Piaget's research points out how important it is to make sure one understands a problem not only from one's own point of view as experimenter, but also from the child's point of view as participant. For example, being asked whether a collection of marbles contains more blue marbles or more marbles can be confusing, even to an adult.

Third, many investigators today question the whole notion of stages of development (for example, Brainerd, 1978; Flavell, 1971). Piaget fudged a bit with the concept of *horizontal décalage*, or nonsimultaneous development of skills within a given stage across domains; many investigators believe that development is simply much more domain-specific than Piaget was willing to admit (e.g., Carey, 1985; Keil, 1989). As another example, children master different kinds of conservation problems at different ages, with the differences appearing in a systematic fashion (Elkind, 1961; Katz & Beilin, 1976; Miller, 1976), with conservation of number appearing before conservation of solid quantity, and conservation of solid quantity before weight.

Fourth, many investigators have found Piaget's theory to better characterize children's competencies than their performance (for example, Green, Ford, & Flamer, 1971). Indeed, Piaget (1972) characterized his model as a competency model. For this reason, it may not be optimally useful in characterizing what children are able to do on a day-to-day basis.

Fifth, although Piaget believed that cognitive development could not be meaningfully accelerated, the evidence suggests the contrary (Beilin, 1980; Field, 1987). Piaget probably took too strong a position in this regard.

Finally, some have questioned the emphasis Piaget placed on logical and scientific thinking (for example, Sternberg, 1990c). People often seem less rational and more oriented toward heuristics than Piaget believed (Gigerenzer, Todd, & the ABC Research Group, 1999).

Vygotsky's theory is, at the turn of the century, more in vogue than Piaget's. It better recognizes the important role of the social-cultural environment in intellectual development. And it also suggests how conventional tests may fail to unearth developing intellectual functions that give children added potential to succeed intellectually. Vygotsky's theory is rather vague, however, and much of the recent development has gone considerably beyond anything Vygotsky proposed. Perhaps if he had not died tragically at an early age (thirty-eight years), he would have extensively amplified on his theory.

Cognitive Processes

A related position is that of cognitive theorists (e.g., Anderson, 1983; Miller, Galanter, & Pribram, 1960; Newell & Simon, 1972), who seek to understand intelligence in terms of the processes of human thought and the architecture

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that holds these processes together. These theorists may use the software of a computer as a model of the human mind, or in more recent theorizing, the massively parallel operating systems of neural circuitry (for example, Rumelhart, McClelland, & the PDP Research Group, 1986). Much of the history of this field is relatively recent, simply because much of the "early" development of the field has occurred in recent times. The field today, for example, has advanced quite far beyond where it was thirty years ago. At the same time, the origins of the field go back to early in the twentieth century and even beyond, depending on how broad one is in labeling work as related to this approach.

The Origins of the Process-Based Approach in Spearman's Principles of Cognition

Although some psychologists in the nineteenth century were interested in information processing (e.g., Donders, 1868/1969), the connection between information processing and intelligence seems to have been explicitly drawn first by Charles Spearman (1923), also known for initiating serious psychometric theorizing about intelligence.

Spearman (1923) proposed what he believed to be three fundamental qualitative principles of cognition. The first, *apprehension of experience*, is what today might be called the encoding of stimuli (see Sternberg, 1977). It involves perceiving the stimuli and their properties. The second principle, *eduction of relations*, is what today might be labeled inference. It is the inferring of a relation between two or more concepts. The third principle, *eduction of correlates*, is what today might be called application. It is the application of an inferred rule to a new situation. For example, in the analogy, WHITE : BLACK :: GOOD : ?, apprehension of experience would involve reading each of the terms. Eduction of relations would involve inferring the relation between WHITE and BLACK. And eduction of correlates would involve applying the inferred relation to complete the analogy with BAD. Tests that measure these attributes without contamination from many other sources, such as the Raven Progressive Matrices tests, generally provide very good measures of psychometric *g*.

The Cognitive-Correlates Approach

Lee Cronbach (1957) tried to revive interest in the cognitive approach with an article on "the two disciplines of scientific psychology," and there were some fits and starts during the 1960s in an effort to revive this approach. But serious revival can probably be credited in large part to the work of Earl Hunt. Hunt (1980; Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975) was the originator of what has come to be called the

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cognitive-correlates approach to integrating the study of cognitive processing with the study of intelligence (Pellegrino & Glaser, 1979).

The proximal goal of this research is to estimate parameters representing the durations of performance for information-processing components constituting experimental tasks commonly used in the laboratories of cognitive psychologists. These parameters are then used to investigate the extent to which cognitive components correlate with each other across participants and with scores on psychometric measures commonly believed to measure intelligence, such as the Raven Progressive Matrices tests. Consider an example.

In one task – the Posner and Mitchell (1967) letter-matching task – participants are shown pairs of letters such as "A A" or "A a." After each pair, they are asked to respond as rapidly as possible to one of two questions: "Are the letters a physical match?" or "Are the letters a name match?" Note that the first pair of letters provides an affirmative answer to both questions, whereas the second pair of letters provides an affirmative answer only to the second of the two questions. That is, the first pair provides both a physical and a name match, whereas the second pair provides a name match only.

The goal of such a task is to estimate the amount of time a given participant takes to access lexical information – letter names – in memory. The physical-match condition is included to subtract out (control for) sheer time to perceive the letters and respond to questions. The difference between name and physical match time thus provides the parameter estimate of interest for the task. Hunt and his colleagues found that this parameter and similar parameters in other experimental tasks typically correlate about −.3 with scores on psychometric tests of verbal ability.

The precise tasks used in such research have varied. The letter-matching task has been a particularly popular one, as has been the short-term memory scanning task originally proposed by S. Sternberg (1969). Other researchers have preferred simple and choice reaction time tasks (for example, Jensen, 1979, 1982). Most such studies have been conducted with adults, but some have been conducted developmentally with children of various ages (e.g., Keating & Bobbitt, 1978).

The Cognitive-Components Approach

An alternative approach has come to be called the *cognitive-components approach* (Pellegrino & Glaser, 1979). In this approach, participants are tested in their ability to perform tasks of the kinds actually found on standard psychometric tests of mental abilities – for example, analogies, series completions, mental rotations, and syllogisms. Participants typically are timed and response time is the principal dependent variable, with error rate and pattern-of-response choices serving as further dependent

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initiation, the approach has little to show for itself by way of useful or at least marketable products. Perhaps this is because it never worked quite the way it was supposed to. For example, Sternberg (1977) and Sternberg and Gardner (1983) found the individual parameter representing a regression constant showed higher correlations with psychometric tests of abilities than did parameters representing well-defined information-processing components.

BIOLOGICAL BASES OF INTELLIGENCE

Some theorists have argued that notions of intelligence should be based on biological notions, and usually, on scientific knowledge about the brain. The idea here is that the base of intelligence is in the brain and that behavior is interesting in large part as it elucidates the functioning of the brain.

Classical Approaches

One of the earlier theories of brain function was proposed by Halstead (1951). Halstead suggested four biologically based abilities: (a) the integrative field factor (C), (b) the abstraction factor (A), (c) the power factor (P), and (d) the directional factor (D). Halstead attributed all four of these abilities primarily to the cortex of the frontal lobes. Halstead's theory became the basis for a test of cognitive functioning, including intellectual aspects (the Halstead-Reitan Neuropsychological Test Battery).

A more influential theory, perhaps, has been that of Donald Hebb (1949). Hebb suggested the necessity of distinguishing among different intelligences. *Intelligence A* is innate potential. It is biologically determined and represents the capacity for development. Hebb described it as "the possession of a good brain and a good neural metabolism" (p. 294). *Intelligence B* is the functioning of the brain in which development has occurred. It represents an average level of performance by a person who is partially grown. Although some inference is necessary in determining either intelligence, Hebb suggested that inferences about intelligence A are far less direct than inferences about intelligence B. A further distinction could be made with regard to *Intelligence C*, which is the score one obtains on an intelligence test. This intelligence is Boring's intelligence as the tests test it.

A theory with an even greater impact on the field of intelligence research is that of the Russian psychologist, Alexander Luria (1973, 1980). Luria believed that the brain is a highly differentiated system whose parts are responsible for different aspects of a unified whole. In other words, separate cortical regions act together to produce thoughts and actions of various kinds. Luria (1980) suggested that the brain comprises three main units. The first, a unit of arousal, includes the brain stem and midbrain structures. Included within this first unit are the medulla, reticular

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activating system, pons, thalamus, and hypothalamus. The second unit of the brain is a sensory-input unit, which includes the temporal, parietal, and occipital lobes. The third unit includes the frontal cortex, which is involved in organization and planning. It comprises cortical structures anterior to the central sulcus.

The most active research program based on Luria's theory has been that of J. P. Das and his colleagues (for example, Das, Kirby, & Jarman, 1979; Das, Naglieri, & Kirby, 1994; Naglieri & Das, 1990, 1997). The theory as they conceive it is the PASS theory, referring to *planning, attention, simultaneous processing*, and *successive processing*. The idea is that intelligence requires the ability to plan and to pay attention. It also requires the ability to attend to many aspects of a stimulus, such as a picture, simultaneously, or, in some cases, to process stimuli sequentially, as when one memorizes a string of digits to remember a telephone number. Other research and tests also have been based on Luria's theory (e.g., Kaufman & Kaufman, 1983).

An entirely different approach to understanding intellectual abilities has emphasized the analysis of hemispheric specialization in the brain. This work goes back to a finding of an obscure country doctor in France, Marc Dax, who in 1836 presented a little-noticed paper to a medical society meeting in Montpelier. Dax had treated a number of patients suffering from loss of speech as a result of brain damage. The condition, known today as aphasia, had been reported even in ancient Greece. Dax noticed that in all of more than forty patients with aphasia, there had been damage to the left hemisphere of the brain but not to the right. His results suggested that speech and perhaps verbal intellectual functioning originated in the left hemisphere of the brain.

Perhaps the best known figure in the study of hemispheric specialization is Paul Broca. At a meeting of the French Society of Anthropology, Broca claimed that a patient of his who was suffering a loss of speech was shown post mortem to have a lesion in the left frontal lobe of the brain. At the time no one paid much attention. But Broca soon became involved in a hot controversy over whether functions, in particular speech, are indeed localized in the brain. The area that Broca identified as involved in speech is today referred to as Broca's area. By 1864, Broca was convinced that the left hemisphere is critical for speech. Carl Wernike, a German neurologist of the late nineteenth century, identified language-deficient patients who could speak, but whose speech made no sense. He also traced language ability to the left hemisphere, though to a different precise location, which is now known as Wernicke's area.

Nobel-Prize-winning physiologist and psychologist Roger Sperry (1961) later suggested that the two hemispheres behave in many respects like separate brains, with the left hemisphere more localized for analytical and verbal processing and the right hemisphere more localized for holistic and imaginal processing. Today it is known that this view was an

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oversimplification, and that the two hemispheres of the brain largely work together (Gazzaniga, Ivry, & Mangun, 1998).

Contemporary Approaches. More recent theories have dealt with more specific aspects of brain or neural functioning. One contemporary biological theory is based on speed of neuronal conduction. For example, one theory has suggested that individual differences in nerve-conduction velocity are basis for individual differences in intelligence (for example, Reed & Jensen, 1992; Vernon & Mori, 1992). Two procedures have been used to measure conduction velocity, either centrally (in the brain) or peripherally (e.g., in the arm).

Reed and Jensen (1992) tested brain nerve conduction velocities via two medium-latency potentials, N70 and P100, which were evoked by pattern-reversal stimulation. Subjects saw a black and white checkerboard pattern in which the black squares would change to white and the white squares to black. Over many trials, responses to these changes were analyzed via electrodes attached to the scalp in four places. Correlations of derived latency measures with IQ were small (generally in the .1 to .2 range of absolute value), but were significant in some cases, suggesting at least a modest relation between the two kinds of measures.

Vernon and Mori (1992) reported on two studies investigating the relation between nerve-conduction velocity in the arm and IQ. In both studies, nerve-conduction velocity was measured in the median nerve of the arm by attaching electrodes to the arm. In the second study, conduction velocity from the wrist to the tip of the finger was also measured. Vernon and Mori found significant correlations with IQ in the .4 range, as well as somewhat smaller correlations (around −.2) with response-time measures. They interpreted their results as supporting the hypothesis of a relation between speed of information transmission in the peripheral nerves and intelligence. These results must be interpreted cautiously, however, as Wickett and Vernon (1994) later tried unsuccessfully to replicate these earlier results.

Other work has emphasized P300 as a measure of intelligence. Higher amplitudes of P300 are suggestive of higher levels of extraction of information from stimuli (Johnson, 1986, 1988) and also more rapid adjustment to novelty in stimuli (Donchin, Ritter, & McCallum, 1978). However, attempts to relate P300 and other measures of amplitudes of evoked potentials to scores on tests of intelligence have led to inconclusive results (Vernon, Wickett, Bazana, & Stelmack, 2000). The field has gotten a mixed reputation because so many successful attempts have later been met with failure to replicate.

There could be a number of reasons for these failures. One is almost certainly that there are just so many possible sites, potentials to measure, and ways of quantifying the data that the huge number of possible correlations

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creates a greater likelihood of Type 1 errors than would be the case for more typical cases of test-related measurements. Investigators using such methods therefore must take special care to guard against Type 1 errors.

Another approach has been to study *glucose metabolism*. The underlying theory is that when a person processes information, there is more activity in a certain part of the brain. The better the person is at the behavioral activity, the less is the effort required by the brain. Some of the most interesting recent studies of glucose metabolism have been done by Richard Haier and his colleagues. For example, Haier and colleagues (1988) showed that cortical glucose metabolic rates as revealed by positron emission tomography (PET) scan analysis of subjects solving Raven Matrix problems were lower for more intelligent than for less intelligent subjects. These results suggest that the more intelligent participants needed to expend less effort than the less intelligent ones in order to solve the reasoning problems. A later study (Haier, Siegel, Tang, Abel, & Buschsbaum, 1992) showed a similar result for more versus less practiced performers playing the computer game of Tetris. In other words, smart people or intellectually expert people do not have to work so hard as less smart or intellectually expert people at a given problem.

What remains to be shown, however, is the causal direction of this finding. One could sensibly argue that the smart people expend less glucose (as a proxy for effort) because they are smart, rather than that people are smart because they expend less glucose. Or both high IQ and low glucose metabolism may be related to a third causal variable. In other words, we cannot always assume that the biological event is a cause (in the reductionistic sense). It may be, instead, an effect.

Another approach considers *brain size*. The theory is simply that larger brains are able to hold more neurons and, more important, more and more complex intersynaptic connections between neurons. Willerman, Schultz, Rutledge, and Bigler (1991) correlated brain size with Wechsler Adult Intelligence Scale (WAIS-R) IQs, controlling for body size. They found that IQ correlated .65 in men and .35 in women, with a correlation of .51 for both sexes combined. A follow-up analysis of the same forty subjects suggested that, in men, a relatively larger left hemisphere better predicted WAIS-R verbal than it predicted nonverbal ability, whereas in women a larger left hemisphere predicted nonverbal ability better than it predicted verbal ability (Willerman, Schultz, Rutledge, & Bigler, 1992). These brain-size correlations are suggestive, but it is difficult to say what they mean at this point.

Yet another approach that is at least partially biologically based is that of behavior genetics. A fairly complete review of this extensive literature is found in Sternberg and Grigorenko (1997). The basic idea is that it should be possible to disentangle genetic from environmental sources of variation in intelligence. Ultimately, one would hope to locate the genes responsible for

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intelligence (Plomin, McClearn, & Smith, 1994, 1995; Plomin & Neiderhiser, 1992; Plomin & Petrill, 1997). The literature is complex, but it appears that about half the total variance in IQ scores is accounted for by genetic factors (Loehlin, 1989; Plomin, 1997). This figure may be an underestimate, because the variance includes error variance and because most studies of heritability have been with children, but we know that heritability of IQ is higher for adults than for children (Plomin, 1997). Also, some studies, such as the Texas Adoption Project (Loehlin, Horn, & Willerman, 1997), suggest higher estimates: .78 in the Texas Adoption Project, .75 in the Minnesota Study of Twins Reared Apart (Bouchard, 1997; Bouchard, Lykken, McGue, Segal, & Tellegen, 1990), and .78 in the Swedish Adoption Study of Aging (Pedersen, Plomin, Nesselroade, & McClearn, 1992).

At the same time, some researchers argue that effects of heredity and environment cannot be clearly and validly separated (Bronfenbrenner & Ceci, 1994; Wahlsten & Gottlieb, 1997). Perhaps the direction for future research should be to figure out how heredity and environment work together to produce phenotypic intelligence (Scarr, 1997), concentrating especially on within-family environmental variations, which appear to be more important than between-family variations (Jensen, 1997). Such research requires, at the very least, very carefully prepared tests of intelligence, perhaps some of the newer tests described in the next section.

Evaluation

The biological approach has provided unique insights into the nature of intelligence. Its greatest advantage is its recognition that, at some level, the brain is the seat of intelligence. In modern times, and to a lesser extent in earlier times, it has been possible to pinpoint areas of the brain responsible for various functions. The approach is now probably among the most productive in terms of the sheer amount of research being generated.

The greatest weakness of the approach is not so much a problem of the approach as in its interpretation. Reductionists would like to reduce all understanding of intelligence to understanding of brain function, but it just will not work. If we want to understand how to improve the school learning of a normal child through better teaching, we are not going to find an answer, in the foreseeable future, through the study of the brain. Culture certainly affects what kinds of behavior are viewed as more or less intelligent within a given setting, and again, the biology of the brain will not settle the question of what behavior is considered intelligent within a given culture, or why it is considered to be so.

Another weakness of the approach, or at least of its use, has been invalid inferences. Suppose one finds that a certain evoked potential is correlated with a certain cognitive response. All one knows is that there is a correlation. The potential could cause the response, the response could cause the

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Evaluation

The greatest strength of cultural approaches is their recognition that intelligence cannot be understood fully outside its cultural context. However common may be the thought processes that underlie intelligent thinking, the behaviors that are labeled as intelligent by a given culture certainly vary from one place to another, as well as from one epoch to another.

The greatest weakness of cultural approaches is their vagueness. They tend to say more about the context of intelligent behavior than they do about the causes of such behavior. Intelligence probably always will have to be understood at many different levels, and any one level in itself will be inadequate. It is for this reason, presumably, that systems models have become particularly popular in recent years. These models attempt to provide an understanding of intelligence at multiple levels.

SYSTEMS MODELS

The Nature of Systems Models

In recent times, systems models have been proposed as useful bases for understanding intelligence. These models seek to understand the complexity of intelligence from multiple points of view, and generally combine at least two and often more of the models described above.

The Theory of Multiple Intelligences. Gardner (1983, 1993, 1999) has proposed a theory of multiple intelligences, according to which intelligence is not just one thing, but multiple things. According to this theory, there are eight or possibly even ten intelligences – linguistic, logical–mathematical, spatial, musical, bodily–kinesthetic, interpersonal, intrapersonal, naturalist, and possibly existential and spiritual.

True Intelligence. Perkins (1995) has proposed a theory of what he refers to as *true intelligence,* which he believes synthesizes classic views as well as new ones. According to Perkins, there are three basic aspects to intelligence: neural, experiential, and reflective.

Neural intelligence concerns what Perkins believes to be the fact that some people's neurological systems function better than those of others, running faster and with more precision. He mentions "more finely tuned voltages" and "more exquisitely adapted chemical catalysts" as well as a "better pattern of connecticity in the labyrinth of neurons" (Perkins, 1995, p. 97), although it is not entirely clear what any of these terms means. Perkins believes this aspect of intelligence to be largely genetically determined and unlearnable. It seems to be somewhat similar to Cattell's (1971) idea of fluid intelligence.

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