College Board Report No. 96-03

Correlates of Gender Differences in Cognitive Functioning

GITA Z. WILDER

College Entrance Examination Board, New York, 1996

Technical Note

Please note that studies that attempt to relate biological and/or psychosocial variables to measures of cognitive functioning vary with respect to both the measures of the biological and/or psychosocial variables and the measures of cognitive functioning. In particular, spatial and mathematical ability and performance have been hypothesized to include various different components and have been operationalized in diverse ways, often producing different conclusions about the existence and degree of variability by gender.

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Printed in the United States of America.

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Introduction

This report was originally prepared as a chapter in a book on gender differences in test performance (Willingham and Cole, 1996, in press) and was intended as an overview of the antecedents of such differences. A major catalyst for research interest in the topic of gender differences in performance was the publication in 1974 of Maccoby and Jacklin's, *The Psychology of Sex Differences*, a comprehensive review of more than 1,500 studies. The authors divided the conclusions from these studies into "unfounded beliefs," "open questions," and "fairly well established" differences. The last included female superiority in verbal ability and male superiority in mathematics, visual-spatial ability,[1] and aggression. Although subsequent research has modified or qualified these findings, the book is still cited as a major source of information about gender. Both the Maccoby and Jacklin work and the research that followed it are based largely on data from studies of performance on tests.

Test performance is likely to vary as a function of the samples of test takers included; the age at which the testing takes place; the kinds of analyses that are performed on test results; and the nature of the tests themselves, especially the constructs that underlie them. For these reasons, following the brief overview, of the most current thinking about the gender differences identified by Maccoby and Jacklin is necessarily an oversimplification and can provide only the flavor of the data and the debate that surrounds them.

Put most simply, differences in the performance of men and women on cognitive measures do exist. What continues to be debated is the significance—statistical, social, and educational—of these differences, the nature of trends in the differences over time, and the causes to which such differences may be attributed.

With respect to performance on verbal tests, it would appear that, while women outperform men, particularly in tests that measure writing ability, the superiority of women in this domain has diminished over time. This decrease in women's performance relative to that of men may be, at least in part, a function of changes in the samples in the studies that have contributed to the data over time.

The bulk of attention directed to gender differences in test performance has been in the area of mathematics, mainly because of the importance of mathematics for access to scientific and technical fields. Overall, there are few differences in the mathematics test scores of boys and girls in the elementary grades. Boys begin to outperform girls in junior high school and the differences persist into high school, particularly on tasks that call for problem solving. These differences may be diminishing over time; however, they have not disappeared altogether. Moreover, the differences are particularly apparent at the higher ranges of the score distribution and among highly selective samples of test takers.

Differences in spatial ability are of interest mainly because they are thought to contribute somehow (although the nature of that contribution is not clear) to mathematical ability. In conducting a meta-analysis of 17 studies of spatial ability, Linn and Petersen (1986) divided the tasks that subjects performed into three categories: spatial visualization, spatial perception, and mental rotation. Gender differences favoring males were typically quite small in spatial visualization, considerably larger in spatial perception, and largest in spatial rotation.

Even the brief discussion above shows that the differences vary as a function of the age of the test takers studied, the samples of test takers included (many are self-selected, such as the groups that take tests for admission to college; others are of targeted groups; and a small number are representative of larger populations), and the nature of the tasks they are asked to perform. Moreover, meta-analyses, the statistical combination of results from multiple studies, yield results that diverge from results from individual studies, even of large numbers of individuals.

To illustrate the complexity of the issue, an example from the Willingham and Cole volume is offered here. Cole and Willingham examine the aggregate results from tests administered to 25 independently drawn, nationally representative samples of twelfth-grade students, reported in 74 separate studies using 12 batteries of tests. From these data, Willingham and Cole conclude that there is "no evidence of any consequential differences in the average test performance of young men and women" (Chapter 3, page 3). This is not to suggest that there are no gender differences. Indeed, women outperformed men on verbal measures, and men outperformed women in tests of natural science and geopolitical knowledge. Moreover, the magnitude of these differences, where (grade) trend data were available, changed over time, having been smaller at the fourth-grade level and more spread out in the eighth and twelfth grades.

Looking at more advanced tests, typically used for college admission and placement and taken by a more selected population (not representative of the national population of twelfth-grade students), Willingham and Cole report larger gender differences, mostly favoring men. These results are further complicated by the fact that differences in the subject matter of the test and the testing mode (mainly, multiple-choice and free-response task formats) interacted. That is, there were differences between men and women in some task formats, in some but not all subjects.

[1] The terms 'visuospatial ability', 'visual spatial ability', and 'spatial visualization' all refer to roughly the same phenomenon: the ability to manipulate three-dimensional structures in the mind, typically measured by asking the subject to respond to two-dimensional (paper-and-pencil) representations of these three-dimensional structures and how they might appear in different orientations.

It seems clear from these examples that there *are* differences between men and women in performance on cognitive measures, and that these differences are not easily characterized. However, this report will confine itself to the antecedents of the differences and leave discussion of the nature of the differences to others. The interested reader is referred to the Willingham and Cole volume for a fairer and more extensive treatment of the topic.

Almost any discussion of differences between the genders in cognitive functioning, including whether such differences are an appropriate focus of scientific inquiry, is inherently controversial. Debates rage over virtually every aspect of the issue: whether the differences are meaningful; how they should be studied; whether they should be reported; and, perhaps most consequentially, what causes the differences in the first place.

We may ask why it is necessary to explore potential causes or, at least, antecedents of the gender differences that form the basis for this report. If the differences exist, why should it matter how they came to be? The answer, of course, is that attributions about cause have everything to do with how the differences are treated. If the causes are perceived as relatively immutable, or changeable only over geologic time periods, the response will be inaction and (perhaps reluctant) acceptance. If, on the other hand, the diagnosis is that the causes lie within domains of human effort, those who seek to eradicate the differences will endeavor to devise remedial strategies. Thus, the ways in which we respond to questions about gender differences—and, indeed, the ways in which we pose these questions—have important implications for education, social policy, and parenting.

Attempts to explain the differences between men and women in cognitive functioning fall into two major categories: biological factors and psychosocial factors. The former include genetic influences on cognitive performance, the contribution of sex hormones, and the possibility of differential brain structures. The latter include a wide range of social and psychological factors: sex roles and sex-role stereotypes, socialization processes throughout the life cycle, individual differences, and educational experiences. It is often assumed that the two types of explanation are mutually exclusive; that is, if biological factors are found to explain much of the variance in cognitive functioning, then psychosocial influences are likely to be minimal, and vice versa. In fact, most considered views of the phenomenon (and of the several realms of human functioning that are the subject of similar debate) see the relationship as much more complex and recognize that biological and psychosocial factors interact in the development of human capabilities and individual differences (e.g., Benbow, 1988; Halpern, 1992).

This report offers a broad overview of the three major categories of explanations of gender patterns in cognitive functioning. Two are the major categories introduced above: biological and psychosocial. The third category, explanations that have been attributed to differences in the educational experiences of men and women, is treated separately, in its own section, because while such explanations are most appropriately considered a subset of psychosocial factors, they have special significance in the context of assessing cognitive ability.

Biological Explanations

There are, as Halpern (1992) notes, strong and weak forms of the argument that biology is responsible for the observed differences between men and women. The assertion by Sigmund Freud that "biology is destiny" is clearly a strong statement, and suggests that the courses of individuals' lives are shaped by forces beyond their control. A weaker form of this assertion is that biology creates potential and imposes some limitations on individual abilities, but that environmental factors influence how and to what extent those abilities are engaged and developed. There *are* biological differences between men and women. Whether these differences are significant for understanding differences in cognitive functioning or irrelevant to them is the question that remains to be answered.

Biological explanations center on three biological systems that might be responsible for gender differences in cognitive functioning: (1) genetic or chromosomal determinants of gender-linked behaviors; (2) differences in sex hormones secreted by the endocrine glands; and (3) differences in the structure, organization, and/or function of the brain. Although these three systems are often studied separately, it should be pointed out that they do not function independently of one another. Understanding the contribution of any of the systems individually to a specific function or set of functions is complicated by the fact that the influence of these systems is interdependent. Chromosomes determine the secretion of sex hormones; sex hormones influence brain development as well as the development of reproductive and external genital organs. The central question is whether any—or all—of these biological differences produce or contribute to differences in cognitive functioning.

Genes and Chromosomes

Fetal (and subsequent) development is directed by information coded on genes, which contain all inherited characteristics. This genetic information makes up an individual's *genotype;* traits that an individual exhibits, which are a joint function of genes and environmental influences, make up that individual's *phenotype.* Researchers use observable characteristics (phenotypes) to infer genetic attributes.

The strategies most frequently employed to study genetic influences on cognitive functioning include population studies, family studies, twin studies, and studies of individuals with genetic abnormalities. Population studies involve examining large numbers of individuals to ascertain the relative proportions of women and men with particular abilities. In family studies, researchers observe heritability patterns across generations, between parents and children, or among siblings to determine whether particular characteristics "run in families." Family studies of IQ, for example, have shown that biological relatives often have similar IQs and that the closer the relationship, the higher the correlation between measured IQs and, presumably, the higher the heritability. A recent review of the literature estimates the heritability of IQ among white adults to be between .40 and .60 (Plomin, 1989). Twin studies enable comparisons between individuals with different degrees of genetic similarity (monozygotic or identical twins and dizygotic or fraternal twins).

A problem with inferring heritability from twin studies is that twins reared together are also subject to similar environmental influences, thus clouding the nature-nurture distinction. When twins have been reared apart, it is theoretically possible to examine pairs who share hereditary features but who have been exposed to different environments, although instances of identical twins reared apart are relatively infrequent. Greater similarity between monozygotic than dizygotic twins in some ability is interpreted as support for genetic influences on that ability. Studies of IQ, for example, have typically shown higher correlations for identical twins (in the region of .85) than for fraternal twins (about .60) (Bouchard & McGee, 1981). Finally, observations of individuals with genetic abnormalities have been used to infer genetic influences in individuals without such abnormalities. More data exist that examine the heritability of intelligence than of any other trait (Plomin, 1990) and, while there is a lack of agreement about the magnitude of the hereditary component, there is general agreement that heredity has *some* influence on measured intelligence.

Some researchers have hypothesized that spatial ability is inherited. Vandenberg (1969) obtained high correlations between pairs of twins on measures of the ability to visualize and rotate figures mentally in space (two of four components of spatial ability identified by Vandenberg), suggesting at least the possibility that these components are inherited. However, such findings do not explain gender differences in the abilities in question. One theory advanced to explain the findings is that spatial ability is a gender-linked recessive trait (one that will appear in an individual's phenotype only if the corresponding gene on the matching chromosome pair also carries the trait) carried on the X chromosome. The theory allows for specific quantitative predictions that, following some early experimental support for the hypothesis (Stafford, 1961, 1963), were not sustained in attempts to replicate the early findings (e.g., Bouchard & McGee, 1977). Halpern (1992) concluded that the sex-linked recessive-gene hypothesis was unfounded. She further contended that it is unlikely that a complex multidimensional variable such as spatial ability—comprised as it is of mental rotation, spatial perception, visualization, and spatiotemporal ability—would have a single genetic determinant. The fact that everyone has *some* degree of spatial ability mitigates against its being explained by a single gene.

In his previously cited study of twins, Vandenberg (1969) examined both verbal and spatial abilities and concluded that, while there are heritable components of both, verbal abilities are influenced to a greater degree by environmental factors than are spatial abilities. Vandenberg's conclusions were based on his finding that the degree of similarity (concordance) between the verbal scores of individuals was related in a linear fashion to the individuals' degree of genetic similarity. So, as with IQ and spatial ability, there was greater concordance in the verbal scores of identical twins than of fraternal twins, and of both kinds of twins than of nontwin siblings. Lehrke (1974) proposed a mechanism for the transmission of verbal ability involving sex-linked recessive genes, parallel to the theory advanced to explain gender differences in spatial abilities, based on his observations of familial patterns in particular mental deficiencies. While some mental deficiencies may be transmitted via sex-linked recessive genes, there is no evidence for such a mechanism for verbal ability among individuals of average intelligence.

Another approach to the question of possible genetic contributions to gender differences is to study the cognitive abilities of individuals with chromosomal abnormalities, such as women with Turner's syndrome (women who have only one X (female) chromosome instead of the usual two) or men with female (XXY) gene patterns. Studies of small numbers of individuals (Rovet & Netley, 1979; Money & Ehrhardt, 1972), however, failed to show superior verbal ability in women with Turner's syndrome—although spatial deficiencies have been noted in such women—or in men with two X chromosomes. Thus, the sparse evidence that exists does not support a genetic explanation for gender differences in cognitive functioning.

Sex Hormones

One important and well-known biological difference between men and women is in the relative concentrations of hormones that circulate through the bloodstream and affect behavior in several domains. Three major sex hormones are present in different amounts in men and women. Both genders have discernible quantities of all three: testosterone (popularly regarded as a male hormone), and estrogen and progesterone (female hormones). The relative concentrations of these hormones vary by gender and also at different stages of the life cycle, suggesting that, if influences of these hormones explain gender differences in cognitive functioning, the influences should also vary with age.

During the prenatal period, sex hormones are important determinants of the sex of the fetus. An XY (typical male) chromosomal configuration directs the development of testes. Testes secrete testosterone that, in turn, directs the development of male reproductive and external genital organs. The XX (typical female) pattern produces ovaries and, because of a lack of testosterone, other female organs. There is evidence that the presence or absence of specific sex hormones during particular stages of development also contributes to gender differentiation in the brain as it develops. Most of the evidence related to the influence of hormones on behavior comes from two sources: laboratory studies in which different types and amounts of hormone are manipulated in animals, and studies of naturally occurring abnormalities in human beings. Both have limitations. Results from the former are limited in their applicability to humans (for one thing, hormones appear to be more important determinants of behavior in animals than in humans), and results from the latter may not transfer to individuals who do not have abnormalities (Halpern, 1992).

Studies with animals have suggested that neurons in the brain respond to sex hormones during the prenatal period (e.g., MacLusky & Naftolin, 1981). Prenatal hormones also influence the development of the hypothalamus and of the corpus callosum, the form of which varies according to the sex of the animal. Experiments to assess the effects of these differences on human behavior would be unethical, and so their relationship to differences in cognitive abilities is not clear.

Studies involving humans who were exposed to synthetic hormones before birth (typically androgenic or "male" hormones intended to prevent miscarriage) showed higher levels of aggression, measured via a paper-and-pencil instrument (Reinisch, 1981). The connection between prenatal hormonal exposure and aggression does not, however, speak to any relationship with cognitive abilities. Dalton (1976) found significantly better "number ability" among children whose mothers received high doses of such hormones during pregnancy, a finding that could not be replicated in later research. Researchers have also studied individuals with genetic disorders that subject them to excessive amounts of androgen during the prenatal period. In a study that focused on selected measures of spatial ability Resnick, Berenbaum, Gottesman, and Bouchard (1986) showed that girls—but not boys—with such a disorder scored higher than their relatives who did not have the condition. A "modest" tendency for verbal abilities to exceed spatial skills was found in a study of men with a condition that makes them insensitive to male hormones. This result does not necessarily support a causal relationship between prenatal hormones and cognitive abilities, because boys with the presenting syndrome are usually raised as girls. Finally, studies of women with Turner's syndrome, a condition in which there is not only a single X chromosome but also low levels of male hormones, showed these women to have specific impairments of visuospatial functioning (Hines, 1982; McCauley, Kay, Ito, & Treder, 1987) as well as social problems that the researchers attributed to the same cognitive deficits.

Geschwind and Galaburda (1987) theorized that, in nonimpaired individuals, sex hormones released during the prenatal period are responsible for gender differences in hemispheric dominance which, in turn, create differences in cognitive abilities. The theory holds that high levels of prenatal testosterone slow the growth of neurons in the left hemisphere, resulting in greater right-hemisphere dominance among men than women. (High levels of testosterone are also related to development of the thymus gland, which controls the immune system and is related to such conditions as allergies and asthma.) Since handedness is an index of hemispheric dominance, and left-handedness indicates dominance of the right hemisphere, the theory predicts the much replicated finding of higher rates of left-handedness in men than women, and higher rates of allergies among left-handed than right-handed individuals. The theory also predicts poorer performance by men than women on cognitive tasks believed to be associated with the left hemisphere (i.e., verbal tasks), and better performance on tasks believed to be associated with the right hemisphere (e.g., mathematical and spatial tasks). However, a study that examined androgen levels in blood samples taken from the umbilical cords of nonimpaired girls and then measured the spatial ability of these girls at age six showed that girls with higher levels of prenatal testosterone scored lower on tests of spatial ability (Jacklin, Wilcox, & Maccoby, 1988).

Broverman, Klaiber, Kobayashi, and Vogel (1968) theorized that the central nervous system is activated by sex hormones in a way that facilitates the performance of simple repetitive tasks, but interferes with the performance of more complex tasks, particularly those that require inhibition of an initial response. Moreover, the theory holds that, because female hormones are more "powerful" than male hormones, women are naturally better at simple tasks and men at complex tasks. The theory was criticized both for its specification of tasks as simple and complex (verbal tasks *are* the tasks at which women typically excel, but verbal tasks can run the gamut from simple to highly complex) and, later, for its modeling of neural processes, for which there is little experimental support.

Research on the influence of prenatal sex hormones on cognition is suggestive but not definitive. Prenatal events appear to influence cognitive functioning later in life, although the mechanisms are not clear and it is difficult to disentangle the contributions of genes, hormones, and life experience.

Another set of theories about biological causes of gender differences in cognitive functioning is based on the finding that performance on measures of mathematical and spatial ability starts to diverge for men and women around the time of puberty. This observation has resulted in hypotheses about the influence on cognitive functioning of hormonal events at puberty. As summarized by Halpern (1992), the hormonal mechanisms posited to cause gender differences include (1) differential rates of physical maturation, (2) age at puberty, (3) the concentration of androgens at puberty, and (4) critical hormone concentration at puberty. One meta-analysis of studies related to IQ and maturation (Newcombe & Dubas, 1987) found that children who mature early enjoy a small but reliable advantage in language-related skills just before, during, and after puberty. These findings suggest that verbal abilities benefit from early development, but the hypothesis fails to specify the cognitive mechanisms that might explain the findings or to account for observed differences in spatial abilities.

Waber (1976, 1977) found that, regardless of gender, later-maturing adolescents performed better on tests of spatial ability than did their earlier-maturing age-mates, and Herbst and Petersen (1980) found a similar difference in scores on the Embedded Figures Test, a measure of field independence/dependence. Waber argued that the same hormonal events that are responsible for the timing of puberty are responsible for gender differences in cognitive abilities. Similarly, Sanders and Soares (1986) found that male and female college students' scores on a test of mental rotation were higher for those who recalled maturing late than for those who recalled maturing early. However, more recent reviews of the literature found little support for an association between spatial abilities in particular and age at puberty (Newcombe & Dubas, 1987; Signorella & Jamison, 1986). Moreover, in their review of the development of spatial abilities, Linn and Petersen (1986) found that gender differences in mental rotation exist as early as middle childhood, suggesting that they are present before puberty.

Petersen (1976), Hier and Crowley (1982), and Nyborg (1984, 1990) hypothesized that the development of spatial ability is based on the presence of an optimal level of hormones. Hier and Crowley found that boys with androgen deficiencies at puberty exhibited impaired spatial abilities (but not verbal abilities) compared with nonimpaired adolescent boys, and that different levels of the hormone were associated with the degree of severity of the spatial impairment. Counter to the Linn and Petersen (1986) findings, Hier and Crowley theorized that puberty is a critical period for the development of spatial skills, which depends on sufficient levels of androgens, although they failed to specify either the minimum level of hormones or the mechanism at work in the process.

Petersen's (1976) variation on the theory held that the relative amounts of female and male hormones, rather than the absolute quantity of androgens, is what determines spatial ability. Nyborg (1984, 1990) argued that estradiol, a hormone that is secreted by the ovaries, although it is created through a chemical conversion process from androgens, is the essential element for the development of spatial abilities. According to this theory, men with higher-than-average levels of estradiol, and women with lower levels, will have better spatial skills. Research involving women with Turner's syndrome, and a study that showed that men with lower levels of androgens performed better on spatial tasks than did men with higher levels, provide some support for this theory. Nyborg claimed that prenatal hormones determine an individual's sensitivity to the hormones that are secreted at puberty, implicating both prenatal and pubertal hormonal processes in the development of spatial abilities.

Research has also been conducted on fluctuations in the cognitive abilities of women during the menstrual cycle, looking for, among other things, any clues such fluctuations might provide about the association between hormones and cognitive performance. In fact, some researchers have found systematic variation in women over the course of the menstrual cycle on measures of selected sensory and perceptual abilities, and in their performance on an array of cognitive tasks (speed of reciting a tongue twister, manual dexterity, verbal fluency, mazes, and the rod-and-frame test, to name several that have been studied) (Kimura, 1989). The pattern of these differences suggests a kind of compensatory relationship between verbal and spatial abilities over the course of the menstrual cycle, such that when performance on one set of abilities is high, the other is low. These findings are supported by research with nonhuman mammals. However, monthly fluctuations in the cognitive ability of women do not explain the differences between men and women. Nor is it clear that these variations have any larger significance for understanding cognitive functioning among women.

Brain Structure

There are no gross anatomical differences in the brains of men and women; the cells are identical except for the presence of X chromosomes in many of the cells in women's brains and of Y chromosomes (along with X chromosomes) in the cells of men's brains.

Women's brains are slightly smaller than men's—about 12 percent lighter and 2 percent smaller in circumference at birth (Janowsky, 1989)—owing mainly to the fact that brain size and weight are positively correlated with body size and men are, on average, larger than women. There is no evidence that men's and women's brains differ with respect to complexity. Attempts to link differences between men and women in cognitive performance to features of the brain have focused mainly on the organization of the brain, specifically on differences in the functions for which each hemisphere is specialized, and/or on the structure of the corpus callosum, the band of neural fibers that connects the two halves of the brain. It is well-known that the two sides of the brain control different functions, each half controlling sensory and motor functions for the opposite side. These differences are present at birth (Coren, 1990). Although the division is far from simple, the left hemisphere is more involved in language functions and symbolic and analytic thought processes, whereas the right hemisphere is more involved in spatial functions.

Neuroscientists are divided about whether gender differences in hemispheric lateralization actually exist (McGlone, 1980). There is some evidence from studies of maze learning in rats that gender differences in learning may be related to brain processes that are affected by gonadal hormones in pregnancy (Denenberg, Berrebi, & Fitch, 1988, p. 188). In a review of the five major paradigms used to study cerebral lateralization in children, Hahn (1987) found that most studies failed to show gender differences and, among those that did, some found that the women's brains were more symmetrically organized than the men's, while others found the opposite.

Handedness—that is whether individuals use their right or left hands for most functions—is a topic that has been actively researched both for its own sake and for its potential value in explaining gender differences in cognitive functioning. Handedness is an indirect measure of brain lateralization, that is, of which side of the brain is dominant for particular functions. The incidence of individuals with certain skills, for example, artists, chess masters, performing musicians, is higher among left-handed persons than in the general population (O'Boyle & Benbow, 1990). There is also evidence that left-handed individuals differ from right-handed individuals with respect to some cognitive abilities. For example, left-handed persons are more likely to be mathematically precocious and less able in some verbal tasks. The fact that more men than women are left-handed is, for some, a reason to believe that handedness (or the brain laterality that handedness signals) is responsible for gender differences in cognitive functioning (e.g., Benbow, 1988). For others, the relationship between gender differences in cognitive functioning and handedness is simply an artifact of the statistical association between the two (Braine, 1988; Bryden, 1988).

Using a variety of measures of brain lateralization—dichotic listening and divided visual field tasks, CAT scans, and recorded evoked potentials of individuals with damage to one or the other side of the brain—some researchers have presented evidence to support the theory that, for verbal tasks, women's brains may be organized more bilaterally than those of men (Bryden, 1988; Hines, 1990). The theory has been contested, although Levy (1976) suggested that functioning in a domain is optimized when one side of the brain is specialized, or lateralized, for a particular task (verbal or spatial), presumably because more neurons are apt to be devoted to that function. Men, on the other hand, may be more lateralized for language, with the result that the other, nonlanguage, hemisphere has more "space" for spatial functions. Levy theorized that, in women, verbal functions are more likely to be represented bilaterally, which gives women an advantage in verbal tasks overall because more "neural space" is devoted to those functions, leaving less for spatial functions. Her theory goes on to suggest that bilateral representation is *not* optimal for solving spatial tasks, which is why women perform less well than men in this domain. Known as the Cognitive Crowding Hypothesis, this theory is supported by research based on dichotic listening tasks, EEG patterns, tactile tasks, and some visual and spatial tasks. The contention is supported as well by the finding from clinical studies that recovery from unilateral brain damage is different for men and women, with men showing more impairment than women on verbal tests following left hemisphere damage, and more impairment on spatial tests following right hemisphere damage. Levy also hypothesized that women may, because of the location of verbal functions in both hemispheres, employ a "verbal" strategy when attacking spatial problems. Both of these theories have been contested on the basis of contradictory evidence and criticisms of the methods used in the research, particularly in the measurement of lateralization.

One theory about the cause of gender differences in cerebral lateralization implicates hormones present during the prenatal period (Geschwind & Galaburda, 1987) or differences in the rate of maturation (Waber, 1976). While a link between prenatal hormones and the development of the brain has been demonstrated, the connection to the timing of puberty has not (Halpern, 1992,p. 155).

Some researchers, fueled mainly by research with nonhuman mammals, focused on the corpus callosum as the organizational mechanism responsible for gender differences in cognitive functioning (Denenberg et al., 1988). The corpus callosum is a group of neural fibers that connects the right and left hemispheres of the brain. Studies with animals found that the corpus callosum is generally larger in the male rat than in the female, and that the size of that structure in both genders can be altered by the administration of hormones during the prenatal period (Denenberg et al., 1988). Researchers who found gender differences in the size of the corpus callosum in humans also found that the differences are larger in the posterior portion of the structure (Kimura, 1987) and that the corpus callosum is larger in women than in men (Adler, 1989; Kimura, 1987). At least one researcher believed that the larger corpus callosum reflects more efficient transfer of information between the hemispheres, which contributes, in turn, to verbal fluency, a skill on which women's performance exceeds that of men.

Recently, the use of neuroimaging techniques, specifically, functional magnetic resonance, for studying brain function produced new evidence of differences in the ways in which the brains of men and women function. For example, Shaywitz et al. (1995) found that, although men and women performed equally well on a verbal task involving reading and recognizing rhyme in nonsense words, the mental processes they used involved different areas of the brain. Men used a small area on the left side of the brain in a region typically associated with speech, whereas women used both this area and another on the right side of the brain. Another study (Gur et al., 1995) examined the brain activity of men and women who were, presumably, cognitively at rest. Although the patterns of activity were very similar for men and women, there were small differences in the involvement of the limbic system, the structure that regulates emotions. The authors of both of these studies refused to assign too much practical significance to these differences. While such variations may signal differences in the ways in which men and women perceive the world, no links have been identified between patterns of brain function and performance on cognitive tasks. And both sets of researchers emphasized that the differences they documented must be interpreted in the context of major similarities and a high degree of overlap in the findings for men and women. The significance of these studies is that they illustrate ways in which new techniques for studying brain structure and function may eventually answer some of the currently unanswered questions about similarities and differences between the genders.

Data from the Study of Mathematically Precocious Youth

One of the most prolific researchers pursuing a biological explanation for gender differences in mathematical ability is Camilla Benbow, who continues a tradition begun by Julian Stanley in his study of mathematically precocious youth. Stanley's and Benbow's data focus largely on performance on the mathematics section of the SAT. Benbow's assertions about biological factors are based on analyses of data collected over a period of more than 15 years and representing several hundred thousand 12- and 13-year-olds, the majority of whom were boys. The data revealed substantial and reliable differences favoring boys in performance on the mathematics portion of the SAT.

Benbow (1990) argued that biological factors contribute to gender differences in mathematical precocity for two major reasons. The first is that mathematical precocity (defined by high scores on the mathematical portion of the SAT at a young age) is correlated with physiological characteristics such as left-handedness, myopia, and allergies. The second is that social and educational factors alone do not explain the gender differences. Benbow suggested that cerebral organization, specifically hemispheric lateralization, and prenatal hormones, specifically testosterone level, are possible causes of the gender differences that have consistently appeared in the data she analyzed, although she herself has not collected data on these variables.

Benbow's contentions have been widely disseminated and criticized. Benbow's (1988) reiteration of her position gave rise to 50 pages of peer commentary, much of it critical, some of which is summarized here. One major set of challenges to her conclusions focused on the fact that the talented youth in her sample were a highly select population. Not only were the students identified by means of high test scores, they were also *self*-selected in the sense that not all of the identified students chose to take part in the research program. Both selection processes yielded more boys than girls, and groups of boys and girls that were not directly comparable. For these reasons, the generalizability of Benbow's findings to the larger population is unclear. Becker and Hedges (1988), for example, showed that it is difficult to infer characteristics of the general population from highly select samples because "many different population structures can give rise to rather similar data in the tails [of the distribution]" (p. 183). It is possible, Becker and Hedges asserted, to explain Benbow's findings as a function of differences in variability between men and women, which explanation might lead to other hypotheses about possible causes. Other researchers (e.g., Humphreys, 1988, pp. 195-196; Mackenzie, 1988, pp. 201-202) agreed.

As has already been noted, there is evidence from animal research that gonadal hormones influence the development of neurobehavioral characteristics that exhibit gender differences (Hines, 1988). There is also evidence that hormones influence human characteristics such as visuospatial ability and language lateralization that could be related to mathematical ability. But there are no reliable data that relate hormones directly to mathematical ability. Kimura (1988, p. 200) demonstrated that levels of sex hormones can influence some abilities and that such hormonal influences tend to be selective. One possibility is that the hormones raise ability levels in some skills and lower them in others. Research from Kimura's laboratory suggested that the influence of hormones on cognitive functioning may not be unidirectional, but rather may effect trade-offs between abilities in a given individual.

Critics of some of Benbow's other arguments (e.g., Braine, 1988, p. 185; Bryden, 1988, p. 186) pointed out that her allusions to left-handedness, allergies, and myopia as potential explanations for differences between men and women in performance on the mathematical portion of the SAT are based on correlations that lack causal validity. The characteristics may co-occur in mathematically precocious youth, but it is not clear how or whether they are linked, as Benbow contended, to cerebral organization. Although individuals who are left-handed are somewhat more likely than those who are right-handed to deviate from "the modal pattern of cerebral organization," there appears to some to be little evidence that handedness is systematically related to lateralization of cognitive functions (Bryden, 1988, p. 186, summarizing his own and others' work). Other evidence suggests that gender differences in cognitive functioning may not be the same for right- and left-handed individuals, depending on the level of reasoning ability of the subject. A supporter of Benbow's search for physiological explanations (Harshman, 1988, p. 194) argued that the observed relationship among handedness, gender, and reasoning-related differences cannot be explained by environmental factors alone. In short, while some researchers acknowledge the potential for a biological contribution to the observed gender differences among mathematically precocious youth (Halpern, 1988, p. 192), there is no direct evidence to support Benbow's arguments. These arguments may, in turn, be framed at a level that is too simplistic to tap complex interactions not only among the factors she identified but also among some that she may have omitted. Several critics concluded that Benbow's evidence for physiological bases is, in the words of one, "nonexistent or irrelevant" (Hardyck, 1988, p. 193).

Even among scientists who believe in the sexual dimorphism of complex behaviors (such as the cognitive tasks involved in mathematical reasoning), Benbow is criticized. Here she is taken to task for her seeming eagerness to find simple physiological explanations for what are undoubtedly complex neural phenomena (Goldman-Rakic & Clark, 1988, p. 191). Findings from research with monkeys suggest that biologically based gender differences are transient (that is, they change with maturity), and can interact with environmental forces during development.

Acceptance of a biological point of view raises the possibility of inherited abilities. At least one critic of Benbow's biological explanations for gender differences in cognitive functioning points to the absence of research on heritability (e.g., twin studies) in the evidence cited. Such research might address the relative importance of genetic and environmental factors in the etiology of gender differences in mathematical functioning (Eysenck, 1988, p. 189). But heritability studies constitute only a first step toward the understanding of such differences; a logical next step would be the study of precisely what is being inherited.

Attempts to identify biological constraints on the cognitive potential of either gender do not appear to have produced conclusive results. Direct evidence for biological links to mathematical "ability" is weak, at best. And, as data from neuroscientific studies showed, without clear specification of the ability or abilities in question, the empirical demonstration of any set of links is well-nigh impossible.

Overall, while much of the research is incomplete and the findings tentative, it appears that there may be gender-related differences in the structure and organization of the brain, although the interpretation—and, for some researchers, even the existence—of the differences is still very much open to question. There also appears to be a relationship between gender differences in some cognitive functions and handedness that cannot be explained entirely by environmental factors. Allowing that there may be some basis in biology for certain of the observed gender differences in cognitive functioning, research is a long way from being able to specify the mechanism or mechanisms that produce the differences. It is also likely, as Halpern (1992) and others believe, that gender-related differences in men's and women's brains are themselves influenced by environmental events, a possibility that many proponents of biological explanations ignore or play down.

Social and Psychological Explanations

Even the strongest proponents of the view that gender differences in cognitive functioning are biologically based acknowledge the contribution of social and psychological factors. The list of ways in which the lives of men and women differ in our society is long.

Some of the more verifiable dimensions of the differences involve variations in the occupations and earnings of men and women, their relative participation in specific activities, and their relative risk for particular psychiatric and psychological disorders. For example, despite recent changes in the social roles of men and women and the fact that increasing numbers of women are entering traditionally male occupations, women are considerably less likely than men to major in science, mathematics, or engineering in college and to seek careers in these fields. Women who worked full time in 1989 earned 66 cents for every dollar earned by men, an increase of only 7 cents since 1968. More than 60 percent of all adults currently living below the poverty line in the United States are women. Women are totally absent from professional baseball, basketball, and soccer. Eating disorders (obesity, anorexia, and bulimia) are much more common in women than men, while men are more likely to be diagnosed with attention deficit disorder, mental retardation, and schizoid disorders, among other psychiatric conditions (National Science Foundation, 1990). Still, many of the social and psychological differences are embedded in long-standing patterns of behavior that, despite the efforts of feminists and social reformers, remain part of the "nonconscious ideology" (Bem & Bem, 1976) of gender differentiation. And, while many of the more subtle ways in which men and women are treated differently have been identified and cataloged in recent years, it is possible that some still remain unexamined.

The significance of social and psychological explanations for gender differences in cognitive functioning lies in their capacity for remediation. While there is evidence that hormones and even genes respond to environmental forces, it is far easier to contemplate changing the social practices and interpersonal behaviors that create and maintain differential opportunities for men and women to develop particular abilities. From the perspective of providing boys and girls with opportunities to acquire the full range of cognitive functions that can enable them to lead productive lives in a complex society, social and psychological domains offer the most fertile ground for the cultivation of change.

Social and psychological factors may affect cognitive functioning in several ways. First, differences in the ways that men and women are socialized by their families and other social units may create different experiences that systematically influence cognitive functioning. Thus, boys and girls may be encouraged to fulfill different expectations, perform different tasks, and behave in different ways, each of these differences contributing to differences in measured ability. A second kind of influence has to do with attitudes, interests, and aspirations. With support from the social context, boys and girls make different choices about how they spend their time, the courses they take in school, and the kinds of futures they envision for themselves.

One of the difficulties inherent in examining social and psychological factors is that much of the evidence for a relationship between one or another of these factors and cognitive functioning is based on self-reports and measures of psychosocial constructs with little or no demonstrated validity. Constructs are measured in different ways, and findings often differ as a function of the particular measures employed. It is nonetheless important to examine the evidence for social and psychological influences, because these abound and they suggest potential areas for intervention.

This section considers some of the social and psychological variables on which men and women differ and which have been proposed as mechanisms contributing to observed gender differences not only in test performance but in other areas of cognitive functioning as well. Because of their particular relevance to academic ability, environmental factors related to education and schooling are described in a separate section following this discussion.

Sex Roles and Sex-Role Stereotypes

Sex roles are societal constructions that reflect collective beliefs about the ways in which men and women behave and the ways in which they are expected to behave and even think. Sex-role stereotypes refer to gender-based expectations that have come to be associated with men or women even though empirical evidence may not support such expectations. Both sex roles and sex-role stereotypes exert important influences on behavior, especially on the range of behaviors that is deemed acceptable for members of each gender. Consider, for example, the disproportionate representation of men in mathematics and engineering, and of women among pre- and elementary-school teachers. It is considered less acceptable for men to pursue typically female occupations (nursery school teacher, secretary) than for women to enter traditionally male occupations (mathematics and engineering, law enforcement, building trades). An extensive literature on sex roles and their influence catalogs the many ways in which being a man or a woman is associated with opportunities and limitations on an individual's choice of activities and occupations.

Sex-role stereotypes also affect achievement and achievement-related behaviors. The impact of sex-role stereotypes, according to Halpern (1992), "comes from pervasive life-long influences to conform to a pattern of behavior that is prescribed by sex" (p. 181). Gender differences in cognitive abilities mirror gender stereotypes about those abilities, which makes it very difficult to disentangle the direction of the influence. In a very global sense, "intellectual excellence is ... enmeshed in a pattern of sex-role expectations contrary to the feminine gender-role" (Sherman, 1983, p. 342). For example, Nash (1979) concluded that men and women whose self-concepts were consistent with the gender stereotyping of a cognitive task performed better on that task. Both boys and girls who expressed a preference for being male performed better on a test of spatial abilities than did children who expressed a preference for being female. A longitudinal study of girls in the sixth through eighth grades showed that the view of math as a man's domain was negatively correlated with math achievement at each grade (Tartre & Fennema, 1991). This was, incidentally, the only affective variable on which that study found consistent gender differences, although the correlational nature of the data opens the findings to multiple interpretations.

What makes the learning of sex roles and particularly of sex-role stereotypes significant is the set of findings showing that children's knowledge of stereotypes based on gender affects their behavior. A number of correlational studies have demonstrated that children and adolescents exhibit greater motivation and mastery of subject matter when they regard achievement in those subjects as consistent with their own sex role and concomitantly less motivation and mastery when they view such achievement as consistent with the opposite sex role (Dwyer, 1974; Johnson, 1983; Kelly & Smail, 1986; Sherman & Fennema, 1977). Parents, too, view their children in ways that are consistent with sex-role stereotypes and ultimately convey these views to their children in the form of expectations. In a study in which parents were interviewed within 24 hours of the birth of their first child, fathers and mothers perceived their sons as better-coordinated, stronger, more alert, and hardier and their daughters as softer, more delicate, more awkward, and less attentive (Rubin, Provenzano, and Luria, 1974). Throughout childhood, parents interpret the behavior of their children in stereotypical ways (Fagot, 1981); they want their preschool children to play with gender-appropriate toys (Schau, Kahn, Diepold, & Cherry, 1980) and believe that boys and girls should be raised differently. Parents emphasize the importance of such values as competitiveness, achievement, and control over emotions as important for boys, while emphasizing close supervision of activities and "ladylike" behavior as important for girls (Block, 1983). More recent studies found that these perceptions and expectations have not changed over time despite the efforts of feminists (Brooks-Gunn, 1986; McGuire, 1988).

Systematic research on sex-role stereotyping did not begin until the late 1960s. Although researchers employed a variety of methods to examine beliefs about gender-related attributes, they found considerable consensus in adults' conceptions of the characteristics of men and women (Ruble & Ruble, 1982). Rosenkrantz, Vogel, Bee, Broverman, & Broverman (1968) asked college students to rate the extent to which a long list of characteristics was more typical of men or women and found that the traits attributed to men were largely those termed *instrumental* (e.g., competence, independence, competitiveness), while those attributed to women were largely *expressive* (e.g., emotional, caring, gentle). Studies carried out in the 1980s yielded similar lists of attributes despite the feminist activism of the 1970s (Ruble, 1983; Williams & Best, 1982). Other components of gender-role stereotypes include physical characteristics (strong and sturdy versus dainty and graceful) and occupations (truck driver and chemist versus elementary school teacher and nurse's aide) (Deaux & Lewis, 1984).

In the 1970s, Sandra Bem and other psychologists critical of how the content of sex roles had traditionally been measured, applied the term "androgynous" to individuals who, in self-report measures of personality traits, described themselves as possessing positive elements of both male and female sex-role stereotypes. Androgyny was then related to other variables such as career choice, locus of control, self-esteem, achievement-related behaviors (Taylor & Hall, 1982), and mental health (Whitley, 1983; Whitley & Frieze, 1985).

In a meta-analysis of the research on gender differences in cognitive functioning and sex-role stereotypes, including the notion of androgyny, Signorella and Jamison (1986) found "consistent and significant associations between gender self-concept and cognitive performance" for spatial and mathematical but not for verbal tasks (p. 218). That is, individuals who described themselves as more masculine and/or less feminine performed better on spatial and mathematical tasks than did those who described themselves as more feminine and/or less masculine. The general pattern varied with the type of spatial task, the subjects' ages, and when the research under review was done. For verbal tasks, none of the hypothesized associations between better performance and more feminine self-concept was established, although the trends were in the predicted direction. Nor did the meta-analysis provide support for the hypothesis that androgynous individuals enjoyed an advantage over nonandrogynous individuals on cognitive tasks, although there were fewer studies that employed androgyny measures than studies that relied on more traditional measures of masculinity and femininity.

Socialization Processes

Early sex-role development. There is considerable evidence that adults view boys and girls differently and treat them differently. The social environments in which children spend much of their time provide them with models of people who behave in ways that are consistent with sex-role stereotypes. And, when children enter school, their peers and teachers model and reinforce conformity with the dominant sex-role expectations.

Boys and girls are treated differently from birth (e.g., Golden & Birns, 1976; Block, 1978) and perhaps even before, in an age of increasing knowledge about the gender of unborn children. Adults exposed to an infant arbitrarily labeled as a boy or a girl tend to imbue the infant with qualities that are consistent with the assigned sex (Stern & Karraker, 1989). The adults in this study also interacted with the infants in sex-stereotypical ways, bouncing and playing roughly with the babies they perceived to be "boys" and holding the "girls" close and speaking softly to them. Boy babies are typically handled more than girl babies, while girl babies are spoken to more frequently than boy babies (Lewis & Freedle, 1973).

A study of Israeli parents suggested that parents may also have different expectations based on gender with respect to the cognitive development of their children (Ninio, 1987). In this study, parents of nine-month-old babies were asked when they expected their children to demonstrate the acquisition of selected skills. The results showed that fathers, in particular, gave later estimates than mothers, especially when the child in question was a girl. These data are consistent with data from other studies that show fathers to have more sex-stereotypical expectations for their young children than mothers. For example, fathers are more involved in play with their sons than with their daughters, especially physical play, which fathers rate as more appropriate for boys than girls (Pellegrini, 1987).

Parents are more likely to encourage gross motor activity in baby boys than in baby girls (Smith & Lloyd, 1978). An observational study found that parents of toddlers reacted favorably to sex-stereotypical activities and negatively to "cross-sex" play (Fagot, 1978), and differentially reinforced such activities as playing with blocks or dolls, running and jumping, assisting with household tasks, and physical closeness. Observations of parents and their school-age children in teaching situations revealed that parents demanded higher levels of task performance and independence from boys than from girls, by responding more readily to girls' requests for help (Rothbart & Rothbart, 1976). Parents are also much more likely to interrupt daughters who initiate conversations, while permitting sons to finish their statements before responding (Greif, 1979).

Parents provide their sons and daughters with different kinds of toys. During the preschool years, girls receive significantly more dolls and dollhouses and boys receive more vehicles, building toys, and guns (Lewis, 1986). Among older children, boys are more likely than girls to receive chemistry sets, microscopes, and mathematical games (Graham & Birns, 1979).

Children begin to apply gender-linked labels (boy, girl, lady, man) in their descriptions of themselves and other people as early as age two. As soon as these categories are familiar to them, children start to associate toys, articles of clothing, household objects, and occupations with one gender as opposed to the other (Weinraub et al., 1984). However, even before they verbalize their own gender, children's play behavior reflects "gender-appropriate" game and toy choices, which have been observed in children as young as 18 months (Fagot, Leinbach, & Hagan, 1986). Findings from naturalistic and laboratory studies show that preschool children more frequently choose to play with same-sex than opposite-sex children, and that their play with same-sex children is more involved than their play with those of the opposite sex (Caldera, Huston, & O'Brien, 1989).

Children are exposed to sex-stereotypical behavior through the models that are available to them at home and in school, in the society at large, and in the media. Even very young children spend large amounts of time watching television (Comstock, 1980, p. 99). Analyses of the content of television shows and commercials agree on the finding that media portrayals of men and women are consistent with sex-role stereotypes. By and large, boys and men on television are depicted as active, dominant, and aggressive, while girls and women are presented as passive and engaged in caregiving activities (Calvert & Huston, 1987; Deaux, 1985). Women on television are portrayed much of the time cleaning, cooking, serving food, and caring for babies, while men are more often seen driving, taking part in sports, or working in occupations requiring strength (construction, auto repair) or intellect (scientists, business executives) (Hoyenga & Hoyenga, 1979). And, although there have been changes in the proportion of time women are on screen in television in recent years, women are still more likely than men to be seen in domestic situations and/or advertising household products (Brett & Cantor, 1988; Signorelli, 1989). Researchers have also found that children who are heavy viewers of television have stronger sex-role stereotypes than children who view less frequently, although the direction of the relationship is unclear.

That sex-role models can be powerful influences on children's ideas about gender-appropriate behavior is illustrated by the finding that children who see their parents behaving in nonstereotypic fashion (mothers who work and fathers who assume child care and household responsibilities, for example) hold less sex-stereotyped views of men and women (Carlson, 1984; Selkow, 1984). And girls who have career-oriented mothers are more likely than girls with "traditional" mothers to engage in physically active play and to report higher educational aspirations and less traditional career choices (Hoffman, 1989).

Sex-role socialization during middle childhood and adolescence. Children learn soon after their entry into school that some academic subjects and areas of achievement are considered masculine and others feminine. One study found that children in the second, sixth, and twelfth grades all thought that reading, art and music, and social skills were feminine, while mathematics, mechanical skills, and athletic ability were masculine (Stein & Smithells, 1969). Moreover, by about the third grade, children reliably assess achievement as a male domain. After reading stories about "Anne" and "John," boys *and* girls in the third through twelfth grades rated Anne less positively than John when they both succeeded, but John much less favorably than Anne when they both failed (Hawkins & Pingree, 1978). Other research suggested that children apply sex-role expectations more flexibly as they grow older (Archer, 1984; Meyer, 1980), but that boys hold more sex-stereotyped views than girls (Archer, 1984; Raymond & Benbow, 1986) and are more likely to devalue the achievements of women (Smith & Russell, 1984).

Boys are typically allowed greater freedom and independence than girls. As they grow up, girls are given chores such as cleaning and babysitting that keep them at home, while boys are assigned responsibilities such as running errands that give them access to the larger world (Whiting & Edwards, 1988).

During middle childhood and adolescence, knowledge of sex stereotypes increases, especially in more subtle areas, such as personality and achievement, compared with the more obvious areas (activities, dress, and occupation) that define sex roles among younger children. Williams, Bennett, and Best (1975) found that sex-role stereotyping increased markedly over the elementary school years and into adolescence, and that male stereotypes are learned earlier than female although there is also evidence to suggest that older children may recognize the existence of attributes associated with gender but not necessarily approve of them (Kelly & Smail, 1986).

In a cross-cultural study of school children in Japan, Taiwan, and the United States, children were asked what school subject they liked best. In all three countries, girls more often than boys chose reading and boys more often than girls chose math. Asked to predict how well they would do in the two subjects in high school, boys predicted they would do better in math than girls predicted they would, but there were no gender differences in predictions about reading (Nemerowicz, 1979). More recent data from the International Assessment of Educational Progress (IAEP) showed that gender differences in responses to a statement about whether math is mostly for boys, mostly for girls, or for boys and girls about equally varied considerably by country in ways that were not directly related to male-female differences in math achievement (LaPointe, Mead, & Askew, 1992). Such data support the idea that gender-differentiated attitudes toward math achievement are in part culturally defined. In a study that asked subjects in three grades (fifth, eighth, and eleventh) to read vignettes about boys and girls who were good at math or English, all the subjects rated the children who were good at math less positively than the children who were good at English, but girls who were good at math were rated least positively (Hektner, 1990).

Elementary schools are often described as "feminine" environments, with an emphasis on quiet and conformity. Huston (1983) suggested that, while boys tend to "act out" more in this environment, the culture of the classroom may be even more detrimental to the development in girls of independence and assertiveness. Studies of classroom interactions suggested that teachers reinforce both boys and girls for "feminine" behavior (Brophy & Good, 1974; Oettingen, 1985). At the same time, teachers are more likely to call on boys (Sadker & Sadker, 1994) and to ask boys to demonstrate new materials, especially those that are perceived as "male" items (Serbin, Connor, & Iler, 1979).

Outside of school, boys and girls engage in different activities. Numerous studies examined the leisure pursuits of children and discovered that boys are more likely to take part in sports, build models, and take things apart or fix them, while girls more often read, sew, cook, and tend to collections (Burns & Homel, 1989; Johnson, 1987). Boys are more likely than girls to be involved with video games. Researchers who examined the cognitive consequences of playing video games suggested that many games offer practice in the use of spatial skills (Greenfield & Lauber, 1985). One study showed that both boys and girls showed gains on a test of mental rotation after they played two computer games that engaged their spatial skills (McClurg & Chaille, 1987), suggesting that their greater interest in such games would ultimately give boys an advantage over girls in terms of spatial ability. And, as has been noted, boys are more likely than girls to have toys related to math and science. Moreover, as in school, children tend to play and socialize with same-sex peers, reinforcing behavior, communication patterns, and attitudes that are differentiated by gender.

How are these differences related to gender differences in cognitive functioning? Block (1983) suggested that the toys that boys are given and encouraged to play with (blocks, chemistry sets, model airplanes) foster manipulation, experimentation, and feedback from the physical world, whereas girls' toys (dolls, dress-up clothing, model kitchens) emphasize imitation and offer fewer opportunities for innovation. Moreover, subtle messages from parents may limit girls' opportunities to explore and venture away from the family.

Because adolescence is the time when the performance of girls and boys in mathematics starts to diverge, some researchers linked these differences in cognitive functioning to puberty. However, adolescence is also a time of important and far-reaching changes in the psychological and social experiences of individuals, which may also affect academic achievement. Recently, researchers on adolescence have focused on the timing of puberty as an important mediator of a variety of outcomes among boys and girls. For one thing, early maturers are more obviously sexually differentiated than their later-maturing peers: girls have breasts and boys are larger, more muscular, and gain facial hair. These physical changes may relate to different life experiences that could provide explanations of differences in cognitive functioning that are as powerful as the hormonal explanations discussed earlier. A study of 11-year-old girls (Newcombe, Bandura,

& Taylor (1983) found that girls who matured earlier scored higher on a femininity scale than later-maturing girls. Later-maturing girls, on the other hand, performed better on a test of spatial ability and evinced more "masculine" interests. However, direct evidence for the influence of the timing of maturity on cognitive functioning is neither substantial nor convincing.

Some researchers found that adolescents are even more likely than younger children to respond to environmental pressures to engage in gender-appropriate behavior (Hill & Lynch, 1983). Such behavior may in turn be related to cognitive functioning. Nash (1975), for example, found a relationship between sex-role preference and spatial visualization among 11- and 14-year-olds. Among both boys and girls, a preference for the male sex role was related to greater spatial ability. Halpern (1992) related this finding to the preponderance of boys over girls in the Benbow and Stanley (1980, 1981, 1983) samples. Halpern suggested that, if adolescent girls believe that it is not appropriate for women to excel in mathematics, it is likely that a large number of mathematically gifted girls will decline to take part in talent searches or fail to take advanced math courses. A number of studies have documented a decline in intellectual functioning in girls relative to boys at adolescence, although the size of the decline is small (Campbell, 1976; Marshall & Smith, 1987; Peil, 1990). The trend is most dramatic among children identified as "gifted." Although at least 50 percent of the children identified as gifted in elementary school are girls, less than 25 percent of the junior high school students so identified are girls (Noble, 1987).

How sex roles and sex-role stereotypes develop. Theories that account for the development of sex-role knowledge and sex-role stereotypes parallel the theoretical approaches to overall development. Psychodynamic theories rely most heavily on the mechanism of identification, a process that is largely unconscious. Freud argued that that process was based on biological drives and the ways in which those drives are modified by social constraints, but other psychodynamic theorists posited mechanisms rooted in parent-child interactions (Horney, 1973), sibling relationships (Adler, 1961), or interactions between the developing child and the larger society (Erikson, 1963). Learning theories (e.g., Schwartz, 1978) asserted that children learn about gender roles as they learn about everything else, through the processes of conditioning, that is, through psychological and social experiences that shape their behavior. These events include the pairing of "new" behaviors with established ones (classical conditioning), and the deployment of reinforcement (operant conditioning)—rewards for desired behaviors, and punishment or the withholding of rewards to discourage undesired behaviors.

Social learning theory (Bandura, 1977; Bandura & Walters, 1963) added imitation and vicarious reinforcement to the array of mechanisms for learning sex roles. Children acquire their sex roles through observing and imitating same-sex individuals, through being rewarded or punished for specific behaviors, and through watching others as *they* are rewarded or punished for appropriate or inappropriate behavior. Cognitive theorists (e.g., Kohlberg, 1966) view the acquisition of sex roles as a function of the development of a general understanding about the world through internal mechanisms that interact with societal events. Gender schema theory (Bem, 1981) introduced the idea that gender provides the developing child with a lens or framework that shapes the ways in which events are interpreted and new information is acquired. Once boys and girls have identified themselves as male or female, they learn and process information differently through gender schema (Bem, 1981; Martin & Halvorson, 1987).

Individual Differences

Some researchers have examined gender differences in cognitive functioning as a function of other individual differences that vary by gender. These differences might be considered the causes or covariates of differences in cognitive functioning. While many features differentiate men and women, only four are discussed here because of their frequent mention in relation to gender differences in academic performance: aggression, achievement motivation, causal attributions about success and failure, and cognitive styles. It should be noted that each of these, as is true of many of the variables invoked to explain differences in cognitive functioning, accounts for relatively small proportions of the variance in such functioning.

Aggression. Aggression has been accorded the most research attention among the traits and behaviors that vary by gender. Many studies reported the same phenomenon: men engage in more physical and verbal aggression from early childhood through adulthood; adolescent boys are 10 times more likely than adolescent girls to be involved in violent crime (U.S. Department of Justice, 1990). Aggression follows a developmental course that is roughly similar for boys and girls. Over the preschool years, physical aggression is gradually replaced by verbal aggression (Goodenough, 1931). And as children start to understand intentions, during the elementary grades, they are more likely to focus their aggression on individuals who have acted deliberately to hurt them (Hartup, 1974). Nonetheless, at about the same time that children become aware of sex-role expectations, aggression begins to decline in girls but not boys (Fagot & Leinbach, 1989). Many studies documented the fact that physical aggression is much more likely to occur in boy-

boy interactions than in boy-girl or girl-girl interactions (Barrett, 1979; Maccoby & Jacklin, 1980). Cross-cultural studies revealed similar patterns (Whiting & Edwards, 1988). In adolescence, boys continue to respond directly and often physically to provocation while girls who are provoked tend to respond in indirect or concealed ways, through exclusion or the spread of malicious gossip (Cairns, Cairns, Neckerman, Ferguson, & Gariepy, 1989). Starting in adolescence, aggression becomes a highly stable personality characteristic. Aggression in childhood is positively correlated with convictions for criminal behavior among adult men and women, although the absolute rates of conviction are considerably lower for women (Huesmann, Eron, Lefkowitz, & Walder, 1984).

Because gender differences in aggression are apparent early in life and across cultures, most researchers believe that there are biological mechanisms at work in the etiology of aggressive behavior. The arguments sound very much like those advanced for the development of gender differences in cognitive functioning, implicating prenatal androgens, the organization of the nervous system, and hormones in adolescence. However, environmental factors are also influential in explaining aggression. Aggressive behavior in both boys and girls has been found to be related to features of child rearing, including harsh parental discipline and physical punishment, as well as to gender-differentiated reactions to aggressive acts by children on the part of parents and other adults (Parke & Slaby, 1983; Condry & Ross, 1985). Exposure to violence on television has also been associated with aggressive behavior in children (Bandura, Ross, & Ross, 1961) and extended exposure to violent television during childhood is associated with aggressive behavior in adolescence (Eron & Huesmann, 1980).

Although gender differences in the degree and expression of aggressive behavior have not been linked to gender differences in cognitive functioning, they do offer an interesting parallel. The explanations offered to explain the differences are similar, and the general acceptance by many researchers of an explanatory model that involves an interaction of hormonal and social influences may be instructional for explanations of gender differences in some cognitive abilities.

Achievement motivation. In his attempts to explain individual differences in motivation related to achievement, McClelland (1961) dropped women from his samples because he found that they did not behave in ways that were consistent with his explanatory model. Horner (1972) then focused her attention on women and found that young women suffered from what she termed "fear of success." Condry and Dyer (1976) interpreted the phenomenon as a realistic assessment by achieving women of the difficulties they are likely to encounter. Lenney (1977) concluded that women have lower expectations than men in intellectual domains, and that the academic self-confidence of men is more stable than that of women, for whom social cues and reinforcement are more important. Harter (1983) concluded from her research that men and women have equal motivation to achieve but that men have greater "mastery motivation." More recent work in the area of achievement motivation found that gender differences are linked to the type of task in relation to which motivation is measured. Licht and Dweck (1983) contended that girls display a "helpless achievement orientation," which is responsible for their lower achievement in mathematics because math is an area in which helplessness is more likely than in other achievement domains to undermine performance. Typically, boys perceive themselves as more competent and have higher expectations of success in mathematics, athletics, and mechanical skills. Girls have higher expectations and set higher standards for themselves in English and art (Richardson, Koller, & Katz, 1986; Wolleat, Pedro, Becker, & Fennema, 1980).

Causal attributions about success and failure. Weiner et al. (1971) developed a theory of attribution related to achievement in which they identified four causes to which individuals attribute their success or failure in any achievement domain: ability, effort, luck, and task difficulty. The theory received considerable empirical support (e.g., Weiner, 1979; Frieze, Whitley, Hanusa, & McHugh, 1982). Although researchers disagree about the fundamental cognitive mechanisms at work in arriving at these attributions, it is generally agreed that the differences in the ways in which people make attributions about their successes and failures are related in systematic ways to their expectations about future performance and to achievement motivation in the domain in question. The idea that men and women may make different attributions for their successes and failures has been suggested as a cause of the differential performance of men and women on tests of achievement and ability.

In a meta-analysis of studies that examined gender differences in attributions about success and failure, Whitley, McHugh, and Frieze (1986) found small effect sizes and only two consistent gender differences. Across the studies included in the analysis, men were more likely than women to attribute their performance to their ability, regardless of outcome. Women, on the other hand, were more likely to attribute their achievement—positive or negative—to luck. However, Whitley and her colleagues also concluded that the results of the individual studies were strongly affected by the ways in which attributions were measured and by situational variables such as the task domain and the context of the research. Their conclusion was that the meta-analysis failed to demonstrate gender differences in attributional tendencies of sufficient magnitude to explain gender differences in achievement.

Cognitive styles. Cognitive styles refer to individual differences in preferred ways of organizing and thinking about the world (Messick, 1984). The best-researched cognitive style is that which describes the degree to which individuals are influenced by objects in their visual field, namely, field dependence or independence (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962). Differences in field dependence/independence have been found to be correlated with differences in problem-solving ability, conformity, and concern about the reactions of others. In general, studies have shown that women are more field dependent than men (Witkin et al., 1962). Sherman (1967) argued that gender differences in field independence are an artifact of gender differences in visuospatial ability. Hyde, Geiringer, and Yen (1975) confirmed this relationship in a population of college students to whom a battery of measures was administered: men demonstrated greater field independence and performed better than women on tests of spatial ability and arithmetic, while women performed better on tests of vocabulary and word fluency. Controlling for differences in spatial ability eliminated the gender differences for arithmetic and field independence, but controlling for differences in knowledge of vocabulary did not affect the remaining measures. Examining the phenomena developmentally, Crosson (1984) found that gender differences in field independence and in visuospatial ability also covaried with the age of the subject.

With the exception of aggression, which few researchers have tried to link to academic achievement, the group differences discussed here have been found by at least some researchers to be correlated with academic achievement in one way or another. As in the case of any correlation, it is difficult to assess the direction of the relationship between the variables, or whether both are caused by a third variable.

Explanations Relating to Educational Experiences

Although the dissimilar educational experiences of men and women are, properly, a subset of the larger array of social and psychological variables that may contribute to gender differences in cognitive functioning, a number of differences in the educational experiences of men and women are commonly singled out as particularly relevant. Among those are differential patterns of course taking by boys and girls, differences in education-related experiences and influences, and experiences of the school environment itself. As with biological and psychosocial variables, educational variables do not act in a vacuum. Rather, they are both products of and contributors to many of the factors that have already been discussed.

Course Taking

One set of explanations for gender differences in cognitive functioning, especially on measures of quantitative ability and of achievement in mathematics and science, is based on the fact that women have traditionally taken fewer courses in these areas than men, especially higher-level courses. In recent years, as the gap in course selection in at least some disciplines has narrowed, so has the achievement gap, although not at the same rate as differences in course taking. It is therefore useful to examine trends in course taking and their potential for explaining the achievement gap.

Jones (1984), for example, attempting to explain gender differences in Medical College Admission Test (MCAT) scores, concluded that "the historical performance differences between men and women are no doubt related to different interest patterns reflected in course selection during high school and college." Doolittle (1985, p. 1) argued that differential item functioning (DIF) results can legitimately be regarded as indicators of group differences in preparation, instruction, or interests rather than as evidence of test or item "bias."

Using data from the High School and Beyond (HS&B) database, Ekstrom, Goertz, and Rock (1988) chronicled some of the changes in the school experiences of high school students during the 10-year period of the study (from 1972 to 1982) as part of an effort to explain an observed decline in test scores. For both men and women, the mean number of courses taken in each of the basic areas of the curriculum decreased over the period. During the 10 years in question, the average number of mathematics courses taken by men dropped from 4.22 to 3.88, and by women from 3.63 to 3.52. The decrease was significantly greater for men than for women, effectively narrowing the gap between them. Similar decreases were found for numbers of courses taken in science (from 3.93 to 3.10 for men and from 3.48 to 2.86 for women).

Armstrong (1981), in her analysis for the Women in Mathematics Study of data from the 1977-78 National Assessment of Educational Progress (NAEP), found similar decreases in the gender differences in achievement in mathematics reported in earlier studies. While all the differences favored men, the only statistically significant differences were for advanced courses. Examining achievement in terms of number of math courses taken, Armstrong found that men almost always enjoyed an advantage over women in solving math word problems. She concluded that differences in achievement in mathematics were not solely a function of differences in course taking, nor did they appear to be a function of differences in visuospatial ability. Armstrong suggested that gender differences in mathematics achievement were more likely the result of "differential learning and practice of mathematics outside of school" (p. 369), the choice of different problem-solving strategies by men and women, or personality variables such as motivation and self-confidence.

Using a subset of the data from the same study, Wise (1985) sought to explain the greater gains of men over women in average (mean) mathematics achievement between the ninth and twelfth grades. The strongest predictors of twelfth-grade math achievement in this national population were ninth-grade math achievement (r=.78) and the number of math courses taken in high school (r=.73). Controlling for the number of math courses taken, Wise found that gender differences in achievement were virtually nonexistent, although women who took more advanced math courses in high school appeared to be a more academically select group than men who took such courses. Wise concluded, from an analysis that controlled for math achievement in the ninth grade, that roughly seven-eighths of the relationship between gender and twelfth-grade math achievement could be accounted for by the number of math courses taken and differences in achievement in the ninth grade. Wise identified three additional factors that predicted gains in math achievement: general academic aptitude, interest in math and math-related occupations, and low levels of participation in extracurricular activities. Wise also observed that, in this sample, gender differences in career interests and in math itself were already evident by the ninth grade. These differences served as predictors of gender differences in the number of math courses taken and in math achievement during high school.

Armstrong (1985), in a survey she conducted in 1978 among large samples of 13-year-olds and high school seniors, found similar patterns of mathematics achievement in boys and girls at age 13, but, by grade 12, identified large differences in problem-solving ability favoring boys. She also found only minor differences in number of courses taken in lower-level high school mathematics, but significant differences among seniors in enrollment in trigonometry, precalculus, and calculus. These results were similar to results from the 1977-78 NAEP and reports by Maccoby and Jacklin (1974), although Armstrong's findings showed smaller gender differences in course taking than were reported in earlier studies. Armstrong identified three groups of variables having the greatest effect on taking higher-level mathematics courses: positive attitudes toward math, perceived need for and usefulness of math, and the positive influence of parents, teachers, and counselors.

Differential course taking has been steadily weakening as an explanation for gender gaps in academic achievement. Gender differences in enrollment in mathematics courses, for example, have decreased steadily, at least up to calculus which, according to a 1989 study, was taken by 7.6 percent of boys and 4.7 percent of girls. A 1990 survey by the Council of Chief State School Officers found that there were no gender differences in course taking up to algebra III/precalculus and calculus. In science there were only small differences in the number of courses taken by boys and girls, although their *patterns* of course taking continued to diverge. Girls were more likely to take advanced biology courses and boys to take physics and advanced chemistry. In both math and science, the average number of courses taken increased during the 1980s, but the increase was larger for girls than for boys. By 1992, NAEP results showed that, consistent with the 1990 Chief State School Officers' survey, among high school seniors, girls were taking about as many mathematics courses as boys up to calculus (Mullis, Dossey, Foertsch, Jones, & Gentile, 1991). Between 1990 and 1992, the percentages of girls taking calculus and trigonometry increased significantly, from 2.5 percent to 4.8 percent for calculus and from 13 percent to 18.7 percent for trigonometry. Among the small proportions of twelfth-grade students who had taken calculus, girls demonstrated slightly higher proficiency in mathematics than boys on NAEP assessment exercises (Mullis, et al.).

Education-Related Experiences and Influences

As the gap in course taking has narrowed, in recent years several major publications have examined the possible contribution of other aspects of the educational experiences of boys and girls to the gap that remains on some measures of cognitive functioning.

In 1992, the American Association of University Women (AAUW) published "a major report on girls and education" (Wellesley College Center for Research on Women [CRW], AAUW, 1992), which was a compilation and interpretation of existing research rather than a report of original research. In building their argument that girls are disadvantaged by the education system, the authors documented a variety of ways in which women are underrepresented in decision making about education. For example, in 1990, roughly one-third of all local school board members were women (despite a more than threefold increase over the 10.2 percent representation in 1927). And, despite the fact that 72 percent of all elementary and secondary school teachers were women, women represented only 28 percent of school principals and 5 percent of school superintendents. About 20 percent (nine of the 50) chief state school officers were women, the largest number in "recent years" (CRW, p. 7). The authors noted that eight of the nine women who were chief state school officers were elected by popular vote. CRW researchers also reviewed the process that resulted in the publication of A Nation at Risk (National Commission on Excellence in Education, 1983), which involved the appointment of education commissions and committees as well as the design of special studies. They observed that few women held leadership positions in any of the 35 special groups assembled to study the issues, and that in only two of the groups were at least half of the members women.

"Informal education." The discussion of socialization documented differences in the leisure-time activities of boys and girls; their propensity for spending time, at least up to adolescence, with same-sex peers; and the differential expectations of parents about boys' and girls' achievement and achievement-related behaviors. Clearly, boys and girls have different experiences in *and* outside of school that may combine to influence academic achievement. In the context of science, for example, and consistent with their patterns of course taking, girls are more likely to have experiences that relate to the biological sciences and are less likely to engage in activities involving electricity and mechanics (Kahle & Lakes, 1983). One study reported that, by third grade, 51 percent of the boys and 37 percent of the girls had used microscopes. By eleventh grade, 49 percent of the boys and 17 percent of the girls had used an electricity meter (Mullis & Jenkins, 1988, reported in CRW, 1992, p. 28). These differences are parallelled by the development of increasingly negative views of science, science classes, and science careers by women (Zimmer & Bennett, 1987, cited in CRW, p. 28).

Plans and aspirations. Career plans differ by gender. Even within the fields of science and mathematics, there is disproportional representation in specific areas (National Science Foundation, 1990). Girls are considerably less likely than boys to plan careers in engineering but slightly more likely to aspire to careers in biology. A study of high school seniors in Rhode Island (Dick & Rallis, 1991) found that among students who had taken physics and calculus courses, roughly three times as many of the boys were planning to major in science or engineering (cited in CRW, 1992, p. 27).

Girls who do continue to study science after high school report that encouragement from teachers is very important (CRW, 1992, p. 28), confirming Lenney's (1977) finding that, for girls, achievement motivation is more likely to be sensitive to social cues.

A number of researchers believe that gender differences in self-confidence are strongly related to enrollment in higher-level math and science courses. Several studies found that, beginning in adolescence, students' confidence in their math ability is more highly correlated with performance in that subject than is any other affective variable (Fennema & Sherman, 1977; Reyes, 1984). Not surprisingly, girls tend to doubt their competence in math more often than boys, a difference that increases with age (Dossey, Mullis, Lindquist, & Chambers, 1988). Fennema and Sherman corroborated a drop in both self-confidence and achievement in math among middle school girls (the authors claimed that the drop in confidence preceded the decline in achievement). Boys are also more likely than girls to see themselves using math as adults (Chipman, Brush, & Wilson, 1985). And while all students tend to lose interest in science as they grow older, the decline is greater for girls than for boys.

Experiences of the School Environment

Attempts to document "inequities" experienced by girls in the education system are complicated by the fact that gender disparities in one domain or another often reveal sins of omission rather than sins of commission where girls are concerned. Sins of omission are difficult to document and their effects are even more difficult to demonstrate. For example, more than two-thirds of the students in special education programs in grades K through 8 are boys (CRW, 1992, p. 19). The traditional interpretation of these data is that the incidence of characteristics that may hinder learning (e.g., speech impairment, emotional disturbance) is higher among boys than girls. However, an alternative explanation offered in the AAUW Report (CRW, 1992, p. 9) was that gender differences in incidence may not be so extreme. Rather, the report suggested that the behavioral manifestations of boys that lead to diagnosis and assignment to special programs may be more disruptive of normal classrooms than those of girls. Such an interpretation suggests that girls are less likely than boys to receive the special assistance they might need to succeed in school.

Preschool. The preschool environment, at least according to some observers, is a setting in which sins of omission appear to thrive. Long considered a bastion of androgynous values, preschools focus on training in impulse control, fostering small-muscle development, and enhancing language ability, areas in which girls tend to become proficient earlier than boys. Critics of the view that preschools are relatively free of sex-stereotypical norms and expectations claim that, because girls enter preschool already competent in the aforementioned areas, teachers turn their attention toward boys, whose language scores in particular rise more quickly than those of girls during the preschool years. In addition, many of the preschool activities that boys engage in more frequently than girls—large-motor and exploratory and investigatory activities—are considered "free play" rather than part of the structured curriculum offered to all children. Left to their own devices, girls are less likely to choose such activities over painting, dressing up, and domestic role playing. Although the impact of these influences has not been studied systematically, some observers believe that they presage later differences in the school experiences of boys and girls that may contribute to gender differences in cognitive functioning.

The formal curriculum. Few would argue that the stated curriculum objectives and the materials that support these objectives are fair indicators of what educators consider important for children to learn in school. Since the early 1970s and the emergence of a feminist "voice" in education, many researchers have called attention to the prevalence in schools of sex-stereotypical materials and perspectives, especially in literature and history.

The AAUW (1992) Report asserted that curriculum content received little attention in the national reports on education and education reform that appeared in the 1980s. Reviewing 138 articles on education reform that appeared between 1983 and 1987 in nine professional journals, the authors found only one article that discussed gender equity in the context of curriculum and instruction. However, since the early 1970s, many studies have examined instructional materials for gender bias (e.g., Women in Words and Images, 1972). These studies agreed on the general finding that women are given short shrift in texts and curriculum materials. Specifically, the studies concluded that the books and lessons to which children were exposed provided them with stereotypical views of women and the impression that the accomplishments documented in the curriculum were mainly the province of men (Tetreault, 1987).

These scrutinies of instructional materials were followed by efforts in the late 1970s and early 1980s to develop more inclusive book lists and broader interpretations of history. And, in fact, although funding for projects focusing on gender equity was drastically reduced in the 1980s, some of the earlier efforts bore fruit. The majority of publishers of educational materials adopted guidelines for nonsexist language. Textbooks *did* change. In 1984, workshops sponsored by the National Council of Teachers of Foreign Languages identified six common forms of gender bias in instructional materials: exclusion of women, sex stereotyping of members of both genders, subordination or degradation of women, isolation of materials on women, superficial attention to contemporary issues or social problems, and cultural inaccuracy (Pinkle, 1984, cited in CRW, 1992, p. 63). A review of the research on how books influence children cited 23 studies demonstrating that books do transmit values to young children, that academic achievement for all students was positively correlated with the use of nonsexist and multicultural curriculum materials, and that sex-role stereotyping was reduced among students whose curriculum portrayed both genders in nonstereotypical roles (CRW, p. 64).

However, a 1989 study of books used in English classes in a national sample of high schools found that the 10 most frequently assigned works included only one by a woman (Applebee, 1989). And research on high school social studies texts found that, while more women are now included in these books, they are likely to be a small set of "famous women" or women in protest movements. The researchers documented a lack of "dual and balanced treatment of women and men" and of "women's perspectives and cultures presented on their own terms" (Tetreault, 1987, cited in CRW, 1992, p. 62).

The classroom as curriculum. It may be useful to distinguish, as the authors of the AAUW Report (1992) did between the formal curriculum—the materials used and the explicit learning objectives in a classroom—and the classroom as curriculum—the teaching practices and classroom culture that form the learning environment and that are no less an influence on students than the explicit learning objectives. There is a growing body of evidence that boys and girls receive different treatment at the hands of their teachers. Meece (1987), for example, found that teachers choose boys as classroom helpers more frequently than girls and reinforce gender stereotypes through the nature of the tasks assigned.

Sadker and Sadker (1986, 1994) conducted a three-year study of 100 fourth-, sixth-, and eighth-grade classrooms to address the question of whether boys and girls are treated differently in the context of instruction. Their largely observational effort identified systematic differences in treatment by gender. In all grades and all subjects, boys dominated group discussion. Teachers paid more attention to boys, recognizing them more frequently when they raised their hands to be noticed, but also allowing them to call out while girls sat with their hands raised. Similarly, Kimball (1989) found that teachers interacted more with boys than with girls and that boys were more likely than girls to offer unsolicited answers.

However, the differences were not restricted to the relative amount of attention teachers gave to boys and girls. Sadker and Sadker identified four types of teacher feedback: praise, acceptance, remediation, and criticism. While they documented more feedback overall from teachers to boys than to girls, the differences favoring boys were also larger in the more instructionally useful categories of praise, criticism, and remediation. When teachers provided specific evaluative feedback about a student's performance, the recipient of that feedback was more likely to be a boy than a girl (Sadker & Sadker, 1994).

Grieb and Easley (1984) identified a double standard in the teaching of mathematics, which rewarded white, middle-class boys who were, according to the authors, in-dependent, self-confident, and "creative in their study of mathematics" (p. 317). By not confronting their nonconforming behavior, teachers allowed these boys to operate outside the dominant ethos of the classroom, whereas girls and minority children were held to more conventional standards. These standards emphasized conformity to a view of mathematics as a set of arbitrary procedures to be undertaken in a fixed sequence. The teacher typically required that the student know the algorithm before proceeding with a problem. The model student followed instructions, memorized algorithms and number facts, and did not seek any knowledge beyond that presented. Grieb and Easley observed that the students most likely to resist such instruction were white, middle-class boys who, in their resistance, developed the independence that the authors claimed was required for achievement in higher-level mathematics. It should be noted that teachers are not always aware of the ways in which they interact with students. The teachers in the Sadkers' study, for example, believed that they were treating boys and girls equally (Sadker & Sadker, 1994).

Several research studies documented tendencies, across grades, for teachers to select classroom activities and presentation formats that boys like and in which they excel or are encouraged more than girls. For example, in the context of science lectures, teachers tended to ask substantive questions of boys 80 percent more frequently than they did of girls. And, although teachers tended to include girls more frequently in laboratory question sessions, more of the time spent in science classes was devoted to lectures than to laboratory activities (Tobin & Farnett, 1990).

Peterson and Fennema (1985) examined some instructional correlates of high and low achievement in mathematics among students in 36 fourth-grade classrooms using residualized gain scores from the NAEP mathematics test, administered in December and then in May. Group means were not significantly different for boys and girls at pretest or posttest or with respect to gains. However, the authors distinguished between low- and high-level test items, compared performance on each for boys and girls, and examined the effects of classroom variables on test performance. Although the researchers found that engagement in mathematics activities in the classroom was related to achievement in predictable ways, engagement and nonengagement did not adequately explain gender differences in performance. For example, engagement in competitive mathematics activities was positively related to achievement on low-level items for boys but negatively for girls. Engagement in cooperative mathematics activities was positively related to performance on both low- and high-level items for girls, but negatively related to achievement on high-level items for boys. Engagement in social activities and one-on-one interactions with teachers were negatively associated with achievement on high-level items for girls but had no effect on boys' achievement. These results suggest a set of complex relationships between classroom dynamics and the academic achievement of boys and girls.

Changing the Patterns through Intervention

There is evidence that features of the educational environment and of the differential school experiences of boys and girls can be changed to the advantage of girls. Efforts to provide instruction to girls in areas in which they have been regarded as deficient have been found to reduce gender differences in academic performance, and intervention in the form of modifications of classroom practice or special programs for girls have enjoyed moderate success in changing their attitudes toward school.

Senk and Usiskin (1983) reported success in developing equal facility in boys and girls in writing geometry proofs, in a study that involved nearly 1400 students between the ages of 14 and 17 in 74 high school classes. The schools included students from a range of educational and socioeconomic background, Although girls had scored significantly lower than boys on a pretest of geometry terminology and facts, by the end of the school year (which included special instruction in writing geometry proofs, considered by the authors one of "the most difficult processes to learn in the school mathematics curriculum," p. 188), the adjusted total scores of girls were higher than those of boys on a standardized geometry test. Moreover, on a test of the ability to write proofs, the mean number of correct proofs was also higher for girls than for boys. In contrast to Benbow's and Stanley's findngs showing the largest gender differences among the most able students, in the Senk and Usiskin study, high-achieving boys and girls performed equally well in writing proofs.

Connor and Serbin (1985) found that brief training sessions improved the visuospatial skills of junior high school students. The research showed that there were no gender differences in the ability to profit from the training with respect to at least two of the components of spatial ability—spatial orientation and visualization—and that students who performed relatively poorly on these tasks prior to the training improved more than students who had performed well initially.

Although no relationship has been demonstrated to actual performance in math or science, there is evidence that special intervention programs for girls can change their attitudes, aspirations, and behavior. An ethnographic study of Operation SMART, a program of Girls Inc. devoted to erasing gender inequities in experiences related to achievement in math and science, found that girls who showed initial reluctance to participate in unfamiliar activities in science became active inquirers into a range of topics with "minimal encouragement and modeling" (Nicholson & Frederick, 1991). A three-year study that followed up on participants in an annual four-week summer program in math, science, and sports for minority junior high school girls showed that more girls planned to take math and science courses after participating in the program. The follow-up also confirmed that the girls were actually taking the courses they had planned to take (Campbell, 1990). And a multiyear follow-up of a summer program for high school girls already interested in science showed that the program helped them modify their stereotypes of people who were good at science and strengthened their commitment to pursuing further study and careers in science and math (Campbell, 1990).

Unanswered Questions and Integrative Models

It should be clear from this account of the research on gender differences in cognitive functioning that there is no simple answer to the question of what causes such differences. There is no dearth of hypotheses—biological, social, psychological,—nor of research in the service of those hypotheses. It should also be clear that all three domains are implicated in the etiology of gender differences, in ways that are likely quite complex. Much of the research described in this report considered one or a limited set of antecedents or variables that may contribute to differentiation by gender: androgens in a particular developmental period, parents' attitudes about gender and play, numbers and patterns of courses taken in school. However, those in search of simple mechanisms for what are undoubtedly multiply determined phenomena are apt to be disappointed. At the same time, there continues to be a need for research that at least attempts to disentangle the influences and that searches for specific mechanisms.

A number of researchers, recognizing the interplay of the forces that contribute to gender differences that appear in middle childhood and early adolescence, developed models that attempted to identify the forces and describe the nature of the interplay among them. Typically, the models explored the difficult question of how multiple influences operating over time act and interact to affect the gender differences in cognitive functioning that are of interest here.

Some of the models were based on specific data sets (e.g., Ethington & Wolfle, 1986); others were derived more globally, from the findings of aggregated studies and from theory (e.g., Petersen, 1980). The models varied with respect to the specificity of the outcomes they predicted (e.g., performance on measures of mathematical proficiency, "cognitive performance," career and achievement motivation); the ages on which they focused (middle school students, high school students, students in a specific grade, adults); and in the explanatory variables they considered. One of the largest differences between models is whether they include (or exclude) biological variables. For example, Halpern (1992), Kavrell and Petersen (1984), and Petersen (1980) included biological variables; Ethington and Wolfle, Farmer (1987), Eccles, et al. (1983), Lockheed, Thorpe, Brooks-Gunn, Casserly, and McAloon (1985), Stallings (1985), and Wise (1985) did not. Although a thorough review and comparison of the models is beyond the scope of this report, they are discussed here because their various integrative approaches acknowledge and attempt to account for the ways in which different categories of explanations may interact and contribute to gender differences in cognitive functioning.

One value of these models lies in their inclusion of different classes of variables and their characterization of the causal processes as complex. The models are especially helpful to the extent that they identify targets for intervention. In fact, several of the developers of the models (Eccles, et al. 1983; Stallings, 1985) offer suggestions for intervention based on their own research. Others intend their models to be used as guides for the development of new hypotheses to be tested in future research.

Conclusion

This report has reviewed the current status of the debate and research on the antecedents of gender differences in cognitive functioning. The question of antecedents is not a new one; there are strong research traditions focusing on both the biological bases of gender-differentiated behavior and the social construction of gender. The report only scratches the surface of the two literatures.

It should be evident from the body of the report that there is no simple account of the antecedents of gender differences in cognitive functioning. Nor, despite a large body of literature on the topic, have these antecedents yet been fully explored. Rather, differences surface as the product of multiple forces that interact over time and in complex fashion. There are unquestionably important biological—genetic, hormonal, possibly brain-functional—differences between men and women, which are manifested differently at the various stages of development and are themselves manifestations of complex interactions of genetic, hormonal, and environmental factors. Such biological differences influence and are also subject to the influence of events and processes in the social environment, of which but a small number were explored here. Boy babies and girl babies are treated quite differently from birth. Undoubtedly, some of the observed differences in the behaviors of men and women that are documented in this report are caused by differential expectations and treatment which, in turn, shape further differences in expectations and treatment. Of major importance to the issue of gender differences in cognitive functioning are the dissimilar educational experiences of boys and girls.

That both sides of the equation—the biological and the social—are involved in gender differences in cognitive functioning seems beyond doubt. However, there remain major questions about the ways in which these broad categories of influence interact. Added to the fact that patterns of differences appear to be changing over time, and that gender differences vary as a function of the way in which they are measured, there is good reason to believe that the antecedents of gender differences will remain a fertile field for continuing research.

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