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Sex, Math and Scientific Achievement:

Why do men dominate the fields of science, engineering and mathematics?

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For years, blue-ribbon panels of experts have sounded the alarm about a looming shortage of scientists, mathematicians and engineers in the U.S.—making dire predictions of damage to the national economy, threats to security and loss of status in the world. There also seemed to be an attractive solution: coax more women to these traditionally male fields. But there was not much public discussion about the reasons more women are not pursuing careers in these fields until 2005, when then Harvard University president Lawrence Summers offered his personal observations.

He suggested to an audience at a small economics conference near Boston that one of the major reasons women are less likely than men to achieve at the highest levels of scientific work is because fewer females have “innate ability” in these fields. In the wake of reactions to Summers’s provocative statement, a national debate erupted over whether intrinsic differences between the sexes were responsible for the underrepresentation of women in mathematical and scientific disciplines.

> There is **no simple answer** for why there are fewer women than men in some areas of science.

As a group of experts with diverse backgrounds in the area of sex differences, we welcome these ongoing discussions because they are drawing the public’s attention to this important issue. In this article, we present an analysis of the large body of research literature pertaining to the question of female participation in these fields, information that is central to understanding sex differences and any proposal designed to attract more women to the science and mathematics workforces. Contrary to the implications drawn from Summers’s remarks, there is no single or simple answer for why there are substantially fewer women

than men in some areas of science and math. Instead a wide variety of factors that influence career choices can be identified, including cognitive sex differences, education, biological influences, stereotyping, discrimination and societal sex roles.

It does not take a Ph.D. to see how making fuller use of female talent would go a long way toward increasing the number of scientific workers. In the U.S., for example, women made up 46 percent of the workforce in 2003 but represented only 27 percent of those employed in science and engineering. One reason Summers's comment upset many people was its implication that any attempt to close this gap was futile. If most women are naturally deficient in scientific ability, then what could be done? But this seemingly simple interpretation contains two misconceptions.

First, there is no single intellectual capacity that can be called "scientific ability." (For simplicity, we will often use the term "scientific" to refer to skills important to work in the fields of science, technology, engineering and mathematics.) The tools needed for scientific achievement include verbal abilities such as those required to write complex journal articles and communicate well with colleagues; memory skills such as the ability to understand and recall events and complex information; and quantitative abilities in mathematical modeling, statistics, and visualization of objects, data and concepts.

Second, if women and men did demonstrate differences in these talents, this fact would not mean these differences were immutable. Indeed, if training and experience did not make a difference in the development of our academic skills, universities such as Harvard would be accepting tuition from students under false pretenses.

One of the confusing things about the field of sex differences is that you can arrive at very different conclusions depending on how you decide to assess abilities. Women clearly have the right stuff to cut it academically. They have constituted the majority of college enrollments in the U.S. since 1982, with the attendance gap widening every year since then. Similar trends are occurring in many other countries. Furthermore, women receive higher average grades in school in every subject—including mathematics and science.

Despite their success in the classroom, however, women score significantly lower on many standardized tests used for admissions to college and graduate school. The disparity in male-female enrollment in science and related fields grows larger at advanced levels of the education system. For example, in the late 1990s women represented 40 percent of undergraduates in science at the Massachusetts Institute of Technology but only 8 percent of the faculty.

Defining Sex Differences

Because grades and overall test scores depend on many factors, psychologists have turned to assessing better-defined cognitive skills to understand these sex differences. Preschool children seem to start out more or less even, because girls and boys, on average, perform equally well in early cognitive skills that relate to quantitative thinking and knowledge of objects in the surrounding environment.

Around the time school begins, however, the sexes start to diverge. By the end of grade school and beyond, females perform better on most assessments of verbal abilities. In a 1995 review of the vast literature on writing skills, University of Chicago researchers Larry Hedges (now at North-western University) and Amy Nowell put it this way: “The large sex differences in writing … are alarming. The data imply that males are, on average, at a rather profound disadvantage in the performance of this basic skill.” There is also a female advantage in memory of faces and in episodic memory—memory for events that are personally experienced and are recalled along with information about each event’s time and place.

There is another type of ability, however, in which boys have the upper hand, a skill set referred to as visuospatial: an ability to mentally navigate and model movement of objects in three dimensions. Between the ages of four and five, boys are measurably better at solving mazes on standardized tests. Another manifestation of visuospatial skill in which boys excel involves “mental rotation,” holding a three-dimensional object in memory while simultaneously transforming it [*see illustration above*]. As might be expected, these capabilities also give boys an edge in solving math problems that rely on creating a mental image.

Indeed, of all the sex differences in cognitive abilities, variation in quantitative aptitude has received the most media attention. This popular fascination is, in part, because mastery of these skills is a prerequisite for mathematically intensive disciplines such as physics and engineering. And, as Summers suggested, if women were disadvantaged in these skills, it would go a long way to explaining why women are typically under-represented in these fields. But the data are much less clear-cut.

As we said before, females get higher grades in math classes at all grade levels and also do slightly better on international assessments in algebra, perhaps because of its languagelike structure. But boys shine on the math part of the Scholastic Aptitude Test (SAT)—resulting in a difference of about 40 points that has been maintained for over 35 years. When all the data on quantitative ability are assessed together, however, the difference in average quantitative ability between girls and boys is actually quite small. What sets boys apart is that many more of them are mathematically gifted.

At first, this statement seems almost paradoxical. If boys and girls are, on average, equally skilled at math, how could there be greater numbers of gifted boys? For reasons that are not yet fully understood, it turns out that males are much more variable in their mathematical ability, meaning that females of any age are more clustered toward the center of the distribution of skills and males are spread out toward the ends. As a result, men outnumber women at the very high—and very low—ends of the distribution. Data from the Study of Mathematically Precocious Youth exemplify this phenomenon. In the 1980s one of us (Benbow), along with the late psychologist Julian C. Stanley, who founded this study at the John Hopkins University Center for Talented Youth, observed sex differences in mathematical reasoning ability among tens of thousands of intellectually talented 12- to 14-year-olds who had taken the SAT several years before the typical age.

Among this elite group, no significant differences were found on the verbal part of the SAT, but the math part revealed sex differences favoring boys. There were twice as many boys as girls with math scores of 500 or higher (out of a possible score of 800), four times as many boys with scores of at least 600, and 13 times as many boys with scores of at least 700 (putting these test takers in the top 0.01 percent of 12- to 14-year-olds nationwide).

Although it has drawn little media coverage, dramatic changes have been occurring among these junior math wizards: the relative number of girls among them has been soaring. The ratio of boys to girls, first observed at 13 to 1 in the 1980s, has been dropping steadily and is now only about 3 to 1. During the same period the number of women in a few other scientific fields has surged. In the U.S., women now make up half of new medical school graduates and 75 percent of recent veterinary school graduates. We cannot identify any single cause for the increase in the number of women entering these formerly male-dominated fields, because multiple changes have occurred in society over the past several decades.

This period coincides with a trend of special programs and mentoring to encourage girls to take higher-level math and science courses. And direct evidence exists that specifically targeted training could boost female performance even further. A special course created by engineering professor Sheryl A. Sorby and mathematics education specialist Beverly J. Baartmans at Michigan Technological University, for example, targeted improvement in visuospatial skills. All first-year engineering students with low scores on a test of this ability were encouraged to enroll in the course. This enrollment resulted in improved performance in subsequent graphics courses by these students and better retention in engineering programs, which suggests that the effects persisted over time and were of at least some practical significance for both women and men.

What leads **one little Einstein** to choose electrical engineering and the other law?

The Role of Biology

Decades of data from studies of different animal species show that hormones can play a role in determining the cognitive abilities that males and females develop. For example, during typical prenatal male development, high levels of hormones such as testosterone masculinize the developing brain and result in male-typical behaviors and probably male patterns of cognitive performance.

More recent studies have shown that hormones continue to play a role in cognitive development throughout life. Such changes have been observed in individuals receiving large quantities of male or female hormones in preparation for sex-change surgery. Researchers found, for example, that people undergoing female-to-male hormone treatment show “masculine” changes in their cognitive patterns: improvements in visuospatial processing and decrements in verbal skills.

The human brain is shaped by these hormones, as well as by our genetic inheritance and a lifetime of experiences, so it should not be surprising that numerous differences appear in female and male brains. In general, females have a higher percentage of gray matter brain

tissue, areas with closely packed neurons and fast blood flow, whereas males have a higher volume of connecting white matter tissue, nerve fibers that are insulated by a white fatty protein called myelin. Furthermore, men tend to have a higher percentage of gray matter in the left hemisphere, whereas no such asymmetries are significant in females.

Imaging studies assessing brain function support the notion that females perform better on tasks such as language processing that call on more symmetric activation of brain hemispheres, whereas males excel in tasks requiring activation of the visual cortex. Even when men and women perform the same task equally well, studies suggest they sometimes use different parts of their brain to accomplish it.

It is important to emphasize, though, that finding sex differences in brain structures and functions does not suggest these are the sole cause of observed cognitive differences between males and females. Because the brain reflects learning and other experiences, it is possible that sex differences in the brain are influenced by the differences in life experiences that are typical for women and men.

Ladies' Choice

Of course, even if you're smart, you might not want to be a scientist. Studies of mathematically gifted youth are of special interest to understanding the psychology of career choice because, within this sample, there is little doubt that each boy and girl has the capacity to excel in science. What leads one little Einstein to choose electrical engineering and the other law? A 10-year study of 320 profoundly gifted individuals (top one in 10,000) found that those whose mathematical skills were stronger than their verbal ones (even though they had very high verbal ability) said math and science courses were their favorites and were very likely to pursue degrees in those areas. On the other hand, those kids whose verbal skills were even higher than their math skills said humanities courses were their favorites and most often pursued educational credentials in the humanities and law.

It appears then that highly gifted kids ask themselves, "What am I better at?" rather than "Am I smart enough to succeed in a particular career?" This finding provides some insight into sex differences. Among precocious children, boys more frequently exhibit a "tilt" favoring mathematical and related abilities compared with verbal aptitude. Encouraging more balanced gifted students to keep science and technology fields open as options may help top off the pipeline with more high-achieving female and male students.

It is true that multiple psychological and social factors play a part in determining career direction. People's individual expectations for success are shaped by their perception of their own skills. One factor in forming our self-perception is how authority figures such as teachers and parents perceive and respond to us. A 1992 study by psychology professors Lee Jussim of Rutgers University and Jacquelynne Eccles of the University of Michigan at Ann Arbor found that the level at which teachers rated a student's mathematical talent early in the school year predicted later test scores—even when objective measures of ability were at odds with the teacher's perception. This study and others suggest that stereotypes of science as masculine may prejudice educators against girls from the start.

The Enduring Glass Ceiling

Perhaps most troubling is the thought that a skilled, confident scientist could climb to the top and still face discrimination when she gets there. Nevertheless, plenty of research suggests that people's perception of a job as stereotypically masculine or feminine results in a bias in hiring and compensating candidates or employees who are male and female, respectively. Even though social psychologists agree that the overt sexism that existed decades ago in the U.S. and in many other countries is now rare, they say it has been replaced by unconscious sexism in some situations.

The real-world impact of covert biases on female achievement in science is not well studied because of the shroud of secrecy surrounding peer review, the process by which many aspects of a scientist's career—awarding of grants, acceptance of academic papers for publication and decisions about hiring—are judged by a panel of other, often anonymous, scientists.

There has been one thorough study of the real-world peer-review process. Biologists Christine Wenneras and Agnes Wold of Goeteborg University gained access to the Swedish Medical Research Council's data on postdoctoral fellowship awards only after a battle in court. Shortly before the investigators published their study in 1997, the United Nations had named Sweden the leading country in the world with respect to equal opportunities for men and women. Even so, men dominated Swedish science. At the time, women received 44 percent of Swedish biomedical doctoral degrees but held only 25 percent of postdoctoral positions and 7 percent of professional positions.

What Wenneras and Wold discovered was shocking. Female applicants received lower mean scores in all areas in which they were evaluated: scientific competence, quality of proposed methodology and relevance of the research proposal. It was possible that the women applicants were less qualified. To test this possibility, the investigators computed scientific productivity based on the applicant's total number of publications, number of first-author publications, quality of each publication and number of times other scientific papers cited their work. By these measures, the *most* productive group of female researchers was rated as comparable in ability to the *least* productive male researchers. All other women were rated below all the men. The authors of this study concluded that the peer-review process in what is arguably the most gender-equal nation in the world is rife with sexism. These results provide a strong rationale for making the peer-review process more transparent. Despite these findings, which were published in the top-ranked international scientific journal *Nature*, there has been no progress toward making the peer-review process more open.

> Women work **fewer hours per week** and spend more time on family and household tasks than comparably educated men do.

Finally, we cannot consider success at work without considering the effort needed for families to function and maintain a home. Even when husbands and wives both work full-time, women continue to assume most of the child care duties and to shoulder most of the responsibility for tending to sick and elderly family members. Women work, on average, fewer hours per week and spend more time on family and household tasks than comparably

educated men do. For women, having children is associated with lower income and a reduced probability of attaining tenure. In contrast, men show a slight tendency to benefit professionally when they become fathers. Thus, the different roles women and men play in family care can also explain their differential participation in demanding careers.

Where We Go from Here

If Larry Summers's comments had one appealing feature, it was the benefit of simplicity. If the lack of women in science were a reflection, in part, of lack of ability, then the take-home lesson would seem to be that we can do nothing but accept the natural order of things.

As this article shows, however, the truth is not so simple. Both sexes, on average, have their strengths and weaknesses. Nevertheless, the research argues much could be done to try to help more women—and men for that matter—excel in science and coax them to choose it as a profession. The challenges are many, requiring innovations in education, targeted mentoring and career guidance, and a commitment to uncover and root out bias, discrimination and inequality. In the end, tackling these issues will benefit women, men and science itself.

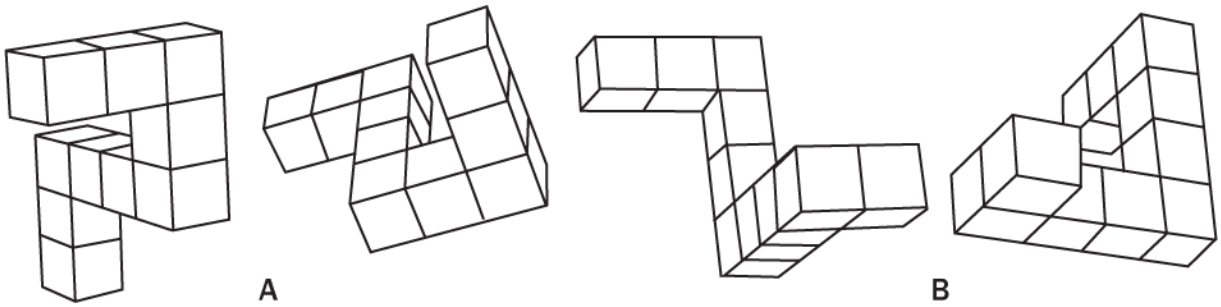
Further Reading

1. Halpern, Diane F.; Benbow, Camilla P.; Geary, David C.; Gur, Ruben C.; Hyde, Janet Shibley; Gernsbacher, Morton Ann. The Science of Sex Differences in Science and Mathematics. Psychological Science in the Public Interest. Aug; 2007 8(1):1–51. [PubMed: 25530726]

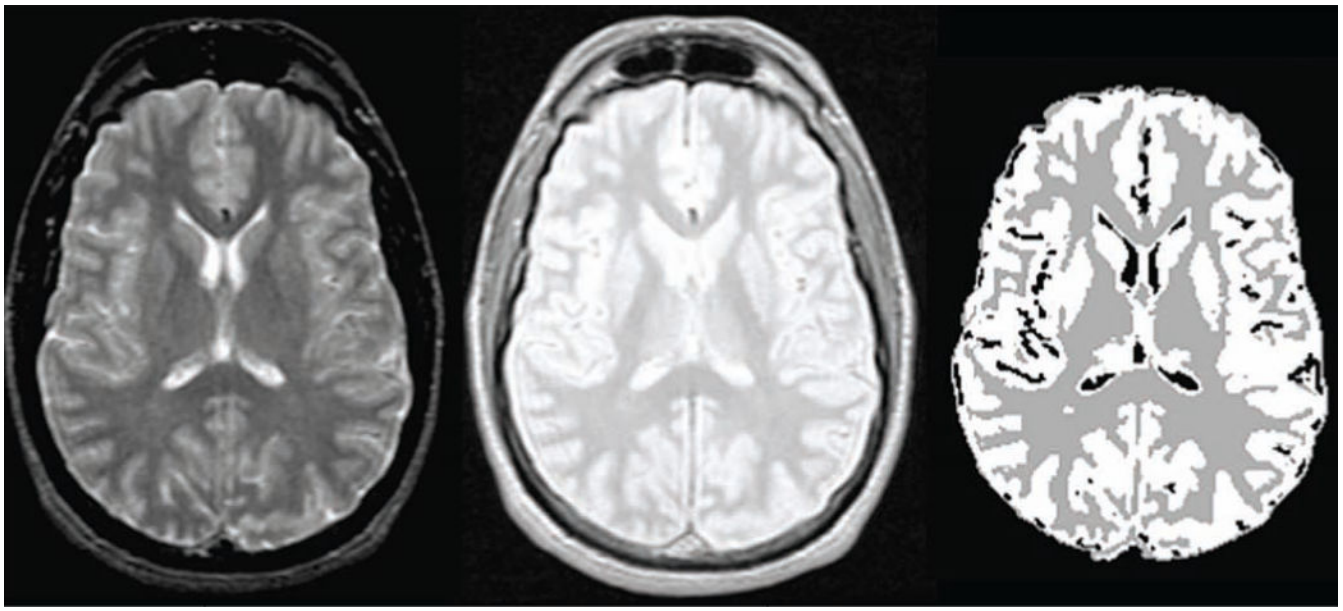
FAST FACTS: Closing the Sex Gap

1. Women, on average, have stronger verbal skills (especially in writing) and better memory for events, words, objects, faces and activities.
2. Men generally are better at mentally manipulating objects and at performing certain quantitative tasks that rely on visual representations.
3. Intervention studies are still in their infancy but suggest both sexes can benefit from targeted training to improve their skill set.

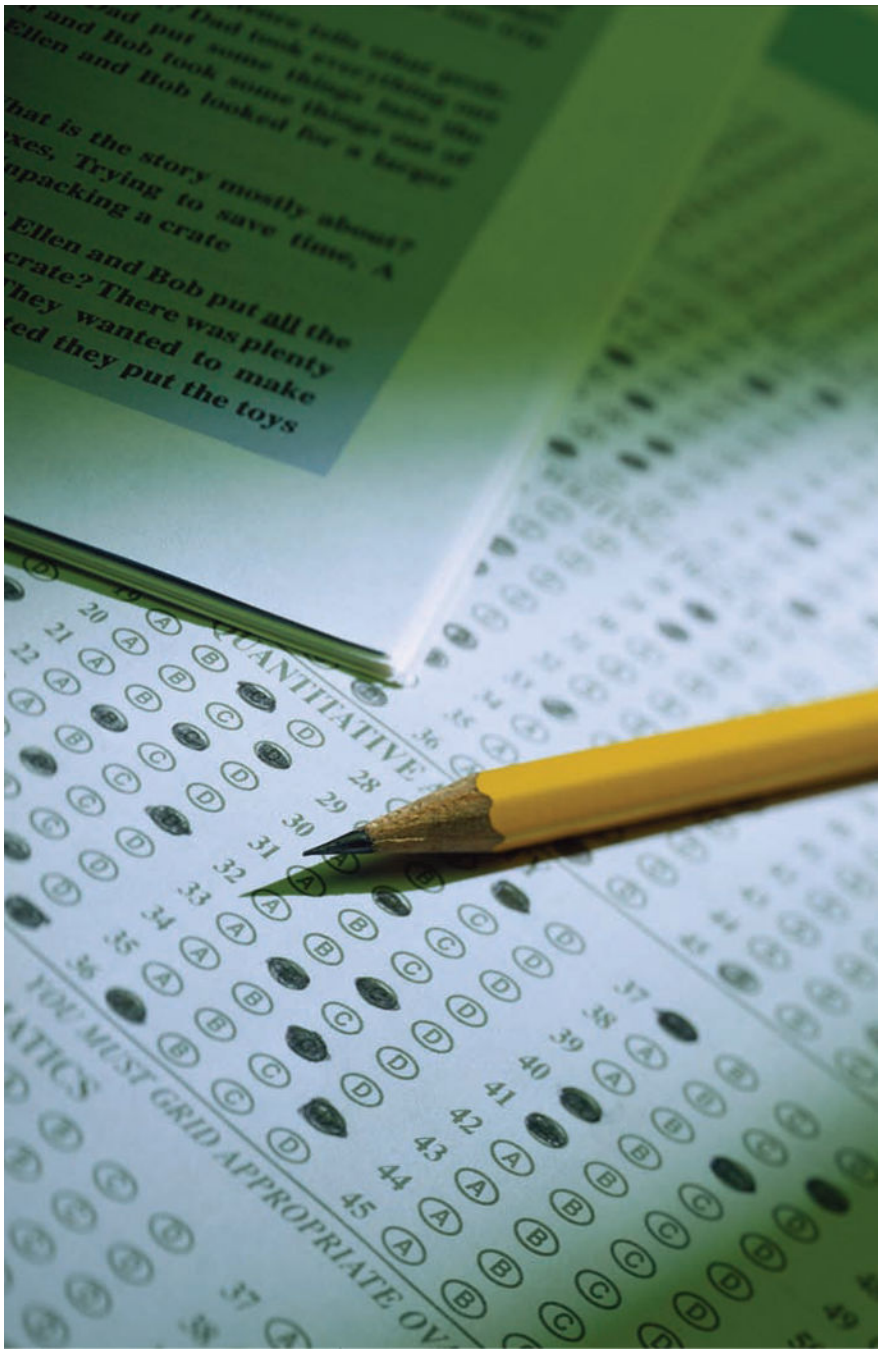
Brains versus brains: Men and women probably have different cognitive strengths as the result of a complex interplay between nature and nurture.



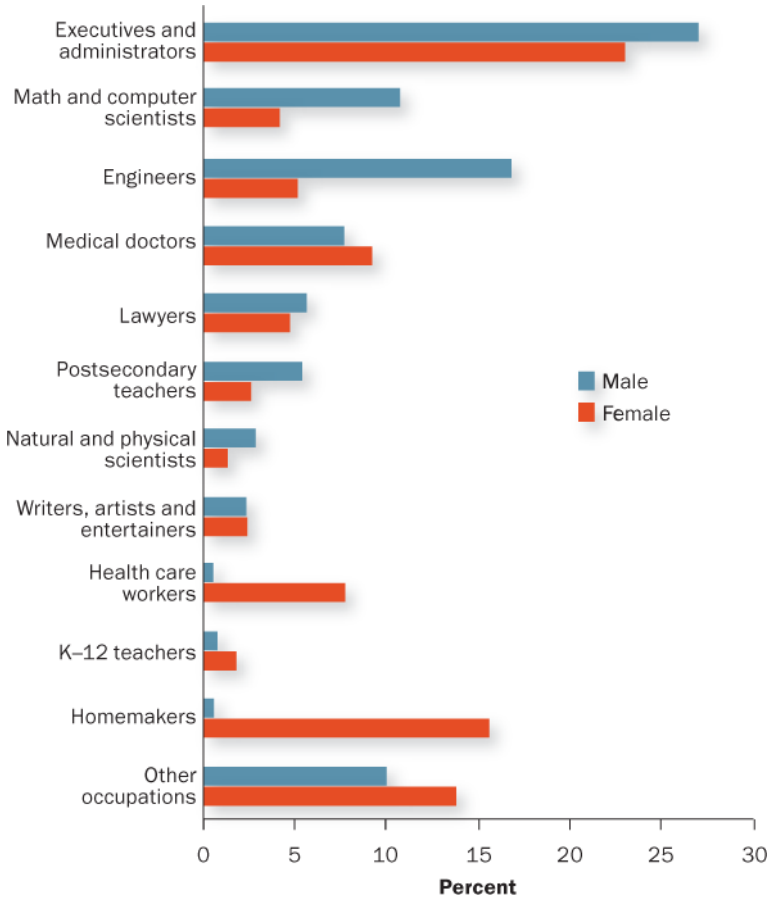
Men generally perform better at “mental rotation” tasks such as this one. The task is to determine if the two figures labeled A and the two figures labeled B could be made identical by rotating them in space.



Sexing the brain: A variety of brain-imaging techniques have allowed researchers to find differences in the structure and function of female and male brains.



Most standardized math tests—such as those of the SAT college admission test—favor male students, even though women receive higher average grades in college math classes.



Sex differences in career choice are apparent even among mathematically gifted children. The graph shows a study on the eventual career choice of boys and girls who ranked in the top 1 percent in mathematical ability.