damental level, asking about priorities and outcomes of particular research projects. It is not desirable to cut off any line of human inquiry. Given a world of limited resources, however, difficult decisions must be made about which projects are to be pursued and which are not. In this context one must ask: Science for whom? Who stands to benefit in terms of wealth and well-being from a particular project, and who does not?

Has Feminism Changed Science?
Schiebinger

9

Physics and Math

EVEN some of the severest critics of studies of science—the physicist Alan Sokal, for example—are willing to acknowledge that examples abound of how gender has molded particular aspects of the life sciences. Many critics of feminism continue to claim, however, a certain purity for math and physics. The challenge goes something like this: Is there a concrete example of gender in the substance of physics or math? Can you point to gender distortion in Newton's laws or Einstein's theory of relativity? If not, the feminist critique is insignificant.

Can we, in fact, identify gender in the physical sciences as we have done in the life sciences? Does the fact that electrons do not have gender in the same way as some of the objects of inquiry in the life and social sciences make physics immune to feminist analysis?

Is Physics Hard?

What is it about physics that so vehemently excludes women? It seems odd that in the biological sciences (where, as we have seen, multiple negative understandings of females as passive or substandard abound) 38 percent of the Ph.D.'s are now awarded to women, while in physics, where far fewer examples of overt gendering have been discovered, only about 13 percent of new Ph.D.'s are women. In 1996 women constituted 3 percent of full professors of physics, 10 percent of associate professors, and 17 percent of assistant professors in Ph.D.-granting departments. In 1994 a full 36 percent of Ph.D.-granting departments had no women faculty members; among departments granting only bachelor's degrees, three-quarters had no women faculty members.[1]

This modern pattern belies women's long participation in the field. Laura Bassi, a physicist at the University of Bologna, was one of two or three women who held positions as professors in the eighteenth century (see Chapter 1). The French physicist Emilie du Châtelet was perhaps the most celebrated woman scientist of the eighteenth century. Her translation of Newton's *Principia mathematica* with a commentary (published after her death in childbirth) remains today the standard French translation of that work.[2] In the twentieth century Marie Curie, Lise Meitner, and Maria Goeppert Mayer all made major contributions, sometimes without the benefit of regular academic positions or even proper laboratories.

The very scarcity of women in physics may be insulating the discipline from feminist critique. There have been very few studies of gender in physics: Evelyn Fox Keller and Helen Longino, who in 1996 published a collection of "classics" in gender and science, named the physical sciences as one of two major areas in need of further work (the other was non-Western sciences).

Scholarship to date on gender in physics has followed several lines of investigation. Sandra Harding has questioned the prestige physics enjoys as the model science. Sharon Traweek and a number of women physicists have emphasized the noisy arrogance of the culture that tends to silence women (see Chapter 4). The physicist Karen Barad has identified a pedagogical style in physics that teaches students to value fun and irresponsibility over meaning and understanding. Others have emphasized how physicists' military ties have held women at a distance. Still others have analyzed how the fortress mentality of "value neutrality" has insulated the physical sciences from gender critique.[3] As noted in the case of archaeology, feminism has made its greatest impact in fields least anchored in positivist epistemologies, fields that have strong traditions of interpretative understanding, including critical and self-reflective thinking.[4] It is worth noting that the proportion of women in particular disciplines follows a hierarchy of perceived prestige of the disciplines, at least in U.S. universities and research communities.

One common explanation for the low numbers of women in physics is that physics is "hard." We are told repeatedly that the physical sciences are hard and that the life sciences, like the humanities and social sciences,

are soft. It is possible to distinguish three different meanings of the supposed hardness of physics. First and foremost, the physical sciences are held to be epistemologically hard. As disciplines, they are considered mathematical, yielding "hard and fast" (also known as "robust") results, and grounded in stringently reproducible (to the eighth digit) fact, while the soft sciences and the humanities are characterized as having considerable breadth, permeable boundaries, and open-ended epistemological structure. In their ethos and telos, the so-called hard sciences are said to be "dispassionate," distant, abstract, and quantitative, while the soft sciences are considered "compassionate" and qualitative, perhaps introspective, and closer to everyday concerns.[5] Physics and the physical sciences are also supposed to be ontologically hard. They study hard, inanimate things—matter in motion—while the life sciences and humanities study soft, animate organisms—plants, animals, humans, and their behaviors. Finally, physics, chemistry, and the other physical sciences are seen as didactically hard, that is, difficult, requiring a high degree of abstract thinking, strong analytical skills, arduous work, and long hours.

The notion that the physical sciences are hard (in all three senses) emerged from a stringent brand of positivism in the early part of the century that has roots going back to the rise of British empiricism in the seventeenth century. Bertrand Russell wrote in the 1920s: "I mean by 'hard' data those which resist the solvent influence of critical reflection, and by 'soft' data those which, under the operation of this process, become to our minds more or less doubtful. The hardest of hard data are of two sorts: the particular facts of sense, and the general truths of logic." Doubt about these data, Russell stated, "would be pathological." Among hard data Russell also included facts of introspection, spatial and temporal relations, and some facts of comparison such as the likeness or unlikeness of two shades of color. Soft data included common beliefs, such as the belief in other people's minds, beliefs that require inference. Following from Russell's definition, the physical sciences are hard because they study things (facts of sense existing separately from us) and employ mathematics. Thus hardness and softness follow a continuum from the study of the external world, where little human inference and emotion are employed, to the study of the human condition and its products. Russell referred to Descartes in this regard, but was also reformulating distinctions made by the early empiricists (David Hume, John Locke, Bishop Berkeley, among others) between primary and secondary qualities. Primary qualities (matter, shape, and motion) were conceived as external to us and thus more "real" than secondary qualities (color, taste, smell) or things known to us through an admixture of human intellect.[6]

"Hardness" is thought to define a hierarchy of the sciences. According to this paradigm, hardness is determined by the degree to which the science is thought to be built on fundamental laws that describe reality. Physics ranks first. According to the Harvard physicist Gerald Holton, theoretical physics is the quest for a "Holy Grail," which is nothing less than "the mastery of the whole world of experience, by subsuming it under one unified theoretical structure." The biologist Scott Gilbert has suggested that modern academic disciplines follow a "Great Chain of Being" with the universe replaced by the university: "*Biology* deals with dirty matter: frogs, snails, puppy dogs' tails, blood, sweat, tears. *Chemistry* deals with matter purified and quantified: 2M H_2SO_4, 4 mg/ml KNO_3. *Physics* deals with idealized matter (when it deals with matter at all): ideal gases, electron probability clouds, frictionless surfaces. (If physics deals too much with material, it falls down a branch of the Chain to become engineering.) Finally, *mathematics* claims to have escaped matter altogether." Many physicists would probably be the first to agree that this hierarchy of the sciences also follows a scale of intelligence: physics is tough, hard, and analytical, not for the faint at heart. Its analytical methods and presumed ability to reduce complex phenomena to simple principles have been taken as the model to which all other sciences should aspire. Even the humanities went through a period of intense scientism in the 1970s, in which the goal was to quantify human endeavor to the greatest extent possible in order to arrive at greater certainty and institutional respect.[7]

The hardness of the science—in what it studies, how it studies it, and the degree of difficulty attributed to it—correlates with prestige, with funding, and, negatively, with the number of women in the field. The National Research Council has found that the more math that is required for a particular job, the higher the pay and the lower the rate of female participation. Conversely, the "softer" the science, the higher the rate of female participation (see Chapter 1). The elaborate gendering of disciplines has led Robert Westman to suggest that the history of science is "androgynous," combining the "hardness" of science with the "softness" of history. The imputed "hardness" of physics may not, however, explain the low numbers of women in the field: the gendering of physics as "hard," "analytical," and so forth is to some extent circular. Which came first, the few women in physics or the notion that it is hard and not welcoming to women? That physics is more difficult than other fields of study is part of its cultural image.[8]

The epistemological hardness of physics may be illusory—the result of narrowing the boundaries of investigation. The cosmologist Martin Rees has suggested that the question of the origins of the universe is "a grand problem but perhaps a more straightforward problem . . . and far easier than anything in the biological world." So while evolutionary geneticists are prone to suffer from "physics envy," it may turn out that biology is ultimately "harder" in the sense that the problems it undertakes encompass complexity not amenable to reduction to a few simple laws.[9]

As the physicist Karen Barad has pointed out, while Newtonian physics might be considered "hard" in a strictly positivist sense, quantum physics seems no "harder" than history or literary criticism considering that the phenomena labeled "elementary particles" depend on extensive instrumental and theoretical interpretation. The notion that physics yields certainty developed from Newtonian classical realism and its vision of a real world existing apart from us and knowable through objective inquiry. This notion of "objectivity" rests on a classical notion that physical properties are observer-independent attributes of objects. In quantum physics, by contrast, what are identified as properties of physical objects (positions and velocities of especially subatomic particles) cannot be attributed to either the object or the measuring instrument alone. The descriptive concepts of physics characterize our interaction with the world; they are not attributes of objects.[10]

The hardness of the physical sciences has been secured by the Cartesian clear and distinct separation of the practice of science from the critical examination of science. Barad sees "getting the numbers out," as the defining feature of contemporary physics and a uniquely American style of physics. She traces the development of this style to the 1920s and early 1930s when theoretical physics gained professional status in the United States: "As the center of physics shifted westward across the Atlantic, the disciplinary boundaries shifted as well: meaning, interpretation, and critical reflection were banished from the domain of physics." In the aftermath of the U.S. victory in World War II, this approach to physics became hegemonic around the world.[11] Questions of meaning, consequences, or social responsibility are not considered to be part of physics proper but to belong to other realms, such as philosophy, ethics, or history.

This may help explain the curious state of modern physics, which at the highest theoretical end couples unreflective materialism to a high-flying metaphysics. There are physicists who regularly see "the face of God" (George Smoot), seek "the God particle" (Leon Lederman), and strive "to understand the mind of God" (Stephen Hawking), thus endowing their quest with religious verve. Robert Wilson has remarked that "both cathedrals and accelerators are build at great expense as a matter of faith."[12] Yet the physicists' god is stripped of ethics and politics. God is "value neutral" in the same way they imagine their science to be. Consequently physicists can ascribe a higher meaning to their quest while still ignoring the social realities of their undertaking.

The "hardness" of physics does not, I think, fully explain the low numbers of women in the field. Sharon Traweek has shown that even though Japanese physics is modeled on the cooperative model of the extended household, women fare little better there than in the rampantly competitive U.S. physics communities. Traweek argues that one model for Japanese physics is the *ie,* or household, where individuals work, not for personal gain, but to maintain the household and its resources in order to pass them intact to the next generation. Decisions in the *ie* are made by consensus, a process Traweek characterizes as more democratic than the one used in the United States. In Japan women are criticized as being too competitive and individualistic, unable to work cooperatively, and not sufficiently nurturing to the newer group members. Traweek makes the interesting point that even though Western categories of gender are reversed in Japan—men are seen as cooperative and nurturing and women as individualist and competitive—women are as excluded from physics there as elsewhere. "There is nothing," she writes, "consistent cross-culturally in the content of the virtues associated with success. We do see that the virtues of success, whatever their content, are associated with men."[13]

Physics and the Military

The prestige physics enjoys has much to do with its success in war. (This is a prestige that may be waning with the end of the Cold War, the end of government-funded big physics—in the decision not to fund the Superconducting Supercollider—and the advent of the government-funded Human Genome Project which is quickly crowning molecular biology the premier science.) World War I was the chemists' war; World War II was the physicists' war. The historian of science Peter Galison has argued that

"after the development of radar and nuclear weapons in World War II, science occupied an unparalleled position of prestige and power."[14]

Wartime science spawned what historians call "big science": large-scale science with multidisciplinary teams engaged in "mission-oriented" research working with capital-intensive equipment. Ties between science and industry characteristic of big science had already begun in the 1920s as physicists and engineers joined efforts to provide hydroelectric power in California, for example. The Manhattan Project represented big science at its apogee: a cooperative, nationally coordinated, government-funded research project involving thousands of the best researchers and directed toward the creation of a single product—an atomic bomb. The physicist Jerrold Zacharias said of this period: "World War II was in many ways a watershed for American science and scientists. It changed the nature of what it means to do science and radically altered the relationship between science and government, the military . . . and industry."[15]

By the 1950s the rapid growth of research and development funded by the military (though pursued chiefly in industrial and university laboratories) was of crucial importance for all those who worked in physics in America. In this period military R&D made up about 90 percent of all federal R&D; in 1986 military R&D continued at about 70 percent of all federal R&D. The physicist Paul Forman estimates that, in the 1980s, 55 percent of all American physicists and astronomers engaged in research and development activities worked on projects of direct military value.[16] As late as 1989, 27 percent of job-seeking physics graduates found work in the military (25 percent took jobs in manufacturing and 24 percent in service industries). In 1995 American universities received $1.3 billion from the Pentagon. In 1998 the United States had not yet achieved its goal of striking a fifty-fifty balance between military and civilian R&D funding. The end of the Cold War hit physics (and mathematics) hard, leading new Ph.D.'s to seek employment in nontraditional fields, such as finance, business, or occasionally even secondary school teaching.[17]

In the postwar period funds for what is called "basic, pure, or fundamental" research increased hand-in-hand with funding for applied research. Though insisting that the value of this research was not tied to its utility, Washington was clear that national security and economic strength rested on superior science. Military funding has shaped science by stimulating the growth of specific fields to the detriment of others. Graduate students in all fields tend to go where the money and jobs are. The Department of Defense's enormous financial resources led to the growth of materials science, cryptology, quantum electronics, and solid state physics, and artificial intelligence and neural networks within computer science.[18]

Is there something about the connection between the military and physics that has discouraged women's participation in physics? Feminist scholars have addressed this question in various ways. One approach has exposed the imagery of male pregnancy and birth surrounding the production and testing of the atomic and hydrogen bombs: the A-bomb was "Oppenheimer's baby," the H-bomb "Teller's baby." Successful bombs were male: "Fat Man" and "Little Boy." Carol Cohn in particular has revealed a world of defense intellectuals in which life and death were permuted, in which bombs became babies and creative people fathered weapons of mass destruction.[19] Cohn notes many reasons for the use of this and other highly sexualized imagery by defense professionals in the 1980s. One is to minimize the seriousness of war and its consequences; bombs viewed as babies seem less threatening. Another is that these images "suggest men's desire to appropriate from women the power of giving life." This type of argument too quickly throws out the baby of science with the bathwater of its military uses: it assumes that women—of all races, times, and cultures—are naturally peace loving, a proposition that does not hold historically.

The connection between physics and the military forged in World War II does shed some light on women's absence from the physical sciences. Early in the century women were often considered too frail to bear "the mental stress of hard study." As such they would hardly have been considered prime candidates for weapons research. While governments sometimes encourage women to enter science, as during the post-Sputnik years and in the 1980s (when the National Science Foundation's miscalculations of a shortage of scientists led to aggressive recruitment of women), this has not been the norm. Before the 1970s women who earned Ph.D.'s in science rarely found jobs in industry or federal scientific agencies. They were confined primarily to women's colleges, where there was virtually no government-funded R&D. Take the example of MIT, a place not known for its friendliness toward women. MIT emerged from World War II with a faculty twice as large as before the war, an overall budget four times as large, and a research budget ten times as large—85 percent of which came from the Atomic Energy Commission. At the end of the war the president of MIT stated: "The value [of MIT] to our country . . . is

parallel with that of a fleet or an army." With no women on the faculty as late as 1960, women were not part of that convoy.[20]

The cultural conventions—variations on the notion that a woman's place is in the home—that have long prohibited women from joining defense activities have not been entirely successful. Lise Meitner, along with Otto Hahn, we should recall, discovered nuclear fission. Later in her life Meitner refused an invitation to work on the atomic bomb at Los Alamos. Although miserable in Stockholm, where she had fled when the Nazis overran Berlin, she declared, "I will not work on your bomb." After the war, despite being called "mother of the bomb," she continued to distance herself from the Manhattan Project and emphasized her opposition to weapons development. In an interview with Eleanor Roosevelt she underscored her opposition to war, stating that "women have a great responsibility and they are obliged to try so far as they can to prevent another war. I hope that the atom bomb not only ended this horrible war—here and in Japan—but that we will use this tremendous energy source for peaceful purposes."[21]

Of course there were other women who worked at Los Alamos in the 1940s, primarily as wives of the men building the bomb. Many of them ran schools, coordinated social events, had babies, cooked, cleaned, and created a somewhat tolerable life in the makeshift desert town. Those women spoke proudly of those years and "affectionately" dedicated their book, *Standing By and Making Do,* to their "husbands and to all the men who made the atomic bomb a reality." Other women, some married to men on the bomb project and some not, served as "computers" (calculating, before their namesakes, solutions to differential and integro-differential equations) at Los Alamos. Still others were scientists in their own right who contributed to the military effort. Across the country, some eighty-five women helped design and construct the atomic bomb. Leona Woods (later Marshall), part of Enrico Fermi's group at the University of Chicago, helped construct detectors for monitoring neutrons from the atomic "pile"—which became the first nuclear reactor. At Columbia University, Maria Goeppert Mayer performed theoretical studies on the thermodynamic properties of uranium hexafluoride and eventually won the Nobel Prize for her nuclear shell model. At Los Alamos, Elizabeth Riddle Graves helped determine what kind of neutron reflector should surround the core of the bomb. Jane Hamilton Hall, who worked as a senior supervisor for nuclear reactors under construction at the Hanford Engineering Works in the state of Washington, eventually became an associate director of Los Alamos National Laboratory. After the war many of these women dropped out of technical jobs.[22]

Women who worked on the Manhattan Project had very different reactions to the destructive force of the bomb. Joan Hinton became so repulsed by the militarization of American physics that she immigrated to China, where in the 1990s she still designed dairy farms. Jean Wood Fuller, in contrast, became an enthusiastic "female guinea pig" for the 1955 atomic bomb test in the Nevada desert. Relishing the blast at 3,500 yards from ground zero, she exclaimed that "women can stand the shock and strain of an atomic explosion just as well as men." Throughout the 1950s she devoted her energies to helping women prepare their homes for a nuclear attack.[23]

Today women still design nuclear bombs. In the late 1980s there were three female bomb designers at Los Alamos. One of them described her work as "being a peeping Tom on Mother Nature" (identifying herself, interestingly, as male in this sexually charged remark). For her a bomb was mainly a design challenge. A somewhat more circumspect woman works among the designers of nuclear warheads at Lawrence Livermore Laboratory. This woman of Japanese descent, whose aunt suffered severe radiation sickness at Hiroshima, justifiably fears nuclear weapons and is disturbed by certain aspects of American nuclear policy, such as the 1950s testing on Pacific Islanders. She defends her work on the grounds of her belief that nuclear weapons will never be used. For her the greatest threat is a nuclear accident, which she hopes to help prevent by perfecting the weapons.[24]

The anthropologist Hugh Gusterson has emphasized that weapons makers run the ordinary gamut of political affiliation, ranging from conservative to liberal, Republican to Democrat. It would be unfair to label them in any particular way. Mostly, however, the people Gusterson studied at Lawrence Livermore Laboratory do not think about or discuss politics. The socialization of scientists into the laboratory is "a process whereby political questions [are] transformed into technocratic questions."[25]

We return to the question why women are so poorly represented in physics and other physical sciences. Apparently not because it is harder conceptually, but rather because of its image, culture, associations, and organization. Many areas of physics during and after the war years became "big science." Women tend not to be in charge of "big science" just as they tend not to be in charge of large organizations such as the armed forces (Sheila Widnall, former Secretary of the Air Force, and Sara Lister, Assistant Secretary of Army Manpower and Reserve Affairs, are among the few) or Fortune 500 companies. Some fields of physics, such as high energy physics in which large accelerators are used, employ up to 500 Ph.D.'s on a single experiment. Big physics projects require teamwork along with what Lew Kowarski of the European Center for Nuclear Research has characterized as military-like hierarchies, autocratic leaders, committees, big money, and the participation of respected and strong personalities.[26] Women have not yet been considered prime candidates to direct these or other big science projects, such as archaeological digs (Chapter 7).

In addition to the question of women's participation in defense-related sciences or in big science, there are other questions about physics that are subject to feminist analysis, such as women's poor representation in theoretical physics—even though it does not depend on access to large pieces of equipment and the kind of organization this equipment breeds. The astrophysicist Andrea Dupree says that it is not the mathematics or physics that keeps women out of cutting-edge conjectural theory but that "extra bit of chutzpah, or aggressiveness or assertiveness." "To be a conjectural theorist," she continues, "requires a certain sense of inner strength, a certain sense of ego and the ability to be verbal, to be articulate, and to be aggressive . . . Theorists love to rank all the other theorists in the world." Women tend to choose problems whose solutions can be demonstrated more directly, perhaps because women have lower status in intellectual communities and their results tend to come under sharper scrutiny. Women often work on small-scale problems, like the surface of the sun, while men choose large-scale problems, like the structure of the universe, not because of inherent gender differences but because men are more likely to have the security and financing needed for large-scale problems, which may require ten to fifteen years to get results.[27]

Feminists are also asking about the relegation of applied physics to second-class status within the hierarchy of subfields, the structure of the physics community, how research groups are organized, how students are educated, how resources are allocated, what questions are considered important, and what answers are accepted.[28] The answers to these questions have a bearing on the content and character of the physical sciences.

In 1996 the unemployment rate for women Ph.D. physicists remained twice that of their male peers (3.8 percent compared with 1.9 percent) after controlling for job experience. As the MIT physicist Vera Kistiakowsky has remarked, "Why would a woman want to get a Ph.D. in physics when she knows she can't get an interesting job and the pay is lousy?" Even in a field as "female-friendly" as medicine, a woman at the top of the profession remarked: "I have to be twice as smart and work three times as hard to get three-fourths the pay and one-half the credit."[29]

Math and the Female Brain

Almost half of the math majors in the United States are women, but only a quarter of the math Ph.D.'s, less than 10 percent of tenured faculty, and 5 percent of tenured professors in Ph.D.-granting departments. More tellingly, in 1992 women held only 5 of 288 tenured positions in the ten most prestigious math departments. Despite near equality at the undergraduate level, potent myths surrounding mathematical genius work to exclude women at the professional level. The mathematician Claudia Henrion has highlighted several of these myths. First, math is a field inhabited by rugged individuals who, working alone, create great mathematics by the sheer strength of their imaginative genius. Second, being a mathematician and being a woman are incompatible: math with its emphasis on mind is not a profession for the females of the species with their incommodious bodies that sometimes become pregnant and give birth. Third, mathematics provides certain, eternal, and universal knowledge arrived at through deductive reasoning and formal proofs.[30]

Henrion's vivid portrayal of gender in the professional world of math goes a long way toward explaining the unease many women feel. Little work has been done, however, on analyzing the content of mathematics from the point of view of gender; my review of the literature yielded but one example. The mathematicians Kenneth Bogart and Peter Doyle have suggested that certain problems have not been solved (or not easily solved) because of sexist assumptions. They cite the "ménage problem," first posed in 1891, which asks for the number M_n of ways of seating "at a circular table n married couples, husbands and wives alternating, so that no husband is next to his own wife." Bogart and Doyle suggest that only the tradition of seating one of the pair first—usually the wife "for courtesy's sake"—made this problem seem difficult and speculate that had it not been for this tradition the problem would have been solved fifty years earlier. The easiest solution requires that both be seated at once. (Bogart and Doyle do not comment on the highly Victorian and rigidly bourgeois character of the problem itself.)[31]

Some feminist critiques of mathematics have emphasized its limitations as a tool. Evelyn Fox Keller, for example, has emphasized that the availability of certain techniques and tools, such as highly developed mathematics, has pushed biology in certain directions to the exclusion of others. The notion of a single central governor, where fundamental characteristics of life derive from a single molecule (Watson's "master molecule"), she argues, has benefited from the fact that these models are more easily manipulated mathematically than models emphasizing global and functional interrelationships.[32]

There is in these critiques of reductionism nothing peculiar to women or to gender. Attempts to connect them to women are situated in an indefensible brand of difference feminism, such as Luce Irigaray's notion that the historical lag in elaborating a theory of fluids (in hydraulics) had to do with an association of fluidity with femininity.[33]

Let me delve here into but one of the debates especially pertinent to the question of women's advancement in science: women's mathematical ability. Math, as we have seen, serves as the critical filter for science careers. The prestige of a science often depends on its degree of mathematization, and the more math required for a particular job, the higher the pay and lower the rate of women's participation. It is popularly believed that boys are good at math while girls are skilled verbally. It is also popularly believed that these skills reflect innate sexual differences—that the differences we see in boys' and girls', men's and women's mathematics ability are a function of sex-specific brain organization.[34]

To what extent do men exceed women in mathematical ability? The German neurologist P. J. Möbius painted a bleak picture in 1900, estimating that it took one million women to find one with mathematical talent. Most women, he claimed, detest mathematics. Möbius was fond of saying that mathematics, which expresses masculine exactitude and clarity, stands in natural opposition to both "womanliness" and love: "A mathematical woman is an unnatural being, she is in a certain sense a hermaphrodite [*Zwitter*]." The great Swedish dramatist August Strindberg, opposing the appointment of Sofia Kovalevskaia as a professor of mathematics at the University of Stockholm in 1889, wrote: "As decidedly as that two and two make four, what a monstrosity is a woman who is a professor of mathematics, and how unnecessary, injurious and out of place she is."[35]

Today the answer to the question "Are men better than women at mathematics?" differs according to which measure one chooses. Standardized tests such as the Scholastic Aptitude Test (SAT), which are seen as measuring raw mathematical ability, favor boys; class grades, often dismissed as measuring mathematical achievement or learned skills, favor girls. Current orthodoxy holds that young boys and girls display few gender differences in mathematics. Differences begin to appear at age thirteen and grow throughout the high school years, with the starkest distinctions in mathematical and spatial ability appearing among high achievers. Nearly all sex-related differences are found among those scoring in the top 10–20 percent of students tested. For example, 8 percent of boys but only 4.5 percent of girls scored at the highest math levels on the National Assessment of Educational Progress (NAEP) test.[36]

Math is one area where naturists and nurturists continue to lock horns. There are a number of unresolved issues: Do gender differences in verbal and math ability actually exist or are they artifacts of the way tests are constructed and administered? Do gender differences in skill result from hard-wired brain structure? Or do they result from social experience, such as parents' and teachers' encouragement, courses taken, gendered stereotypes and expectations, and so forth?

Naturists offer a variety of biological explanations for what they take to be confirmed gender differences. One is the theory of greater male variability. Mathematical ability is taken to be genetic, carried on the X chromosome. Because a male inherits only one X chromosome, male intelligence is said to be highly variable. Female intelligence is considered less variable because a female inherits two X chromosomes, and the intelligence quotient contributed by one X chromosome may cancel out the intelligence quotient contributed by the other. Thus female intelligence, produced by two inherited chromosomes, hovers in a middle range, while male intelligence, unmediated by a second X chromosome, may be high, medium, or low.[37] There are at one and the same time more male geniuses and more male idiots.

A second explanation for greater male achievement in math has to do with degrees of brain lateralization. Studies of brain lateralization suggest that women do poorly in math because their brains are not as highly specialized as men's. Lateralization—the increasing specialization of the two hemispheres of the brain—continues until a child passes through puberty. Boys mature approximately two years later than girls, and thus are likely to have more highly lateralized brains with spatial and verbal functions located in separate hemispheres. (For right-handers, the left side of the brain specializes in verbal skills while the right side specializes in spatial skills.) Bilateralization, or lesser division between the left and right brain, in girls and women creates competition within the hemispheres, thus reducing spatial and mathematical ability. The "cognition crowding" hypothesis suggests that because women's verbal abilities are represented in both hemispheres, verbal processes tend to impinge upon neural space in the right hemisphere that in men is devoted more exclusively to spatial reasoning. Women derive certain benefits from their presumed bilateralization, the greatest being that they have lower incidence of aphasia, or speech disorders, after damage to the left hemisphere.[38]

Brain research has emerged as a hot new field, pushed by new technologies such as functional magnetic resonance imaging and positron emission tomography (PET) that measure changes in cerebral blood flow, allowing researchers to identify more exactly the location of specific brain functions. The neurologist Richard Haier recently PET-scanned male and female students as they solved SAT math problems and found that they used their brains very differently in this regard. High-scoring men (SAT scores of 700 or above) used their temporal lobes intensively—more than either low-scoring men (scores of 540 or so) or high-scoring women. High-scoring women showed no difference in brain activity from low-scoring women, suggesting that the high-scoring men's achievement was associated with effort.[39] The high-scoring men and women performed equally well. Nonetheless, they seem to use their brains differently.

Nurturists offer markedly different explanations for boys' domination of the upper-level test scores. A common one is that a larger percentage of boys than girls take the highest-level math courses offered in high school. A more controversial explanation is that girls tend to employ conventional strategies in solving problems, things they learned in high school, while boys use unconventional strategies, making boys more independent and successful on current tests.[40] Girls' aversion to risk or unwillingness to engage in unconventional problem solving correlates with studies reporting lower self-confidence among young women. Naturists suggest that different approaches to problem solving between the sexes reflect brain organization. Because of girls' brain bilateralization, their strong verbal abilities may prompt them to use verbal cognitive style when solving spatial problems.

The most challenging explanation today is that mathematical aptitude tests are biased. Naturists tend to assume that the SAT is a neutral instrument. But do current tests measure native ability as advertised, or do they favor young men? Take the example of the SAT, prepared by the Educational Testing Service in Princeton, New Jersey, and taken by 1.5

million sixteen-to-eighteen-year-olds annually. The purpose of the test is to predict first-year college performance. As every hopeful high school student knows, the stakes are high. Top scores are required to enter the most prestigious colleges and universities and to receive the best scholarships.

The SAT has two parts: the verbal and the mathematical. Despite the fact that cognitive studies generally show that girls are more verbal than boys, significant gender differences do not show up on the verbal portion of the SAT. Currently boys outscore girls by about 10 points (considered statistically insignificant). This was not always so. Before 1972 girls outscored boys, and they still score higher than boys on the verbal sections of two other major surveys: the NAEP and the National Educational Longitudinal Survey. What happened with the SAT? It has been recognized since 1942 that "intellect can be defined and measured in such a manner as to make either sex appear superior" and that conflicting data regarding sex differences in mental ability "must be attributed to differences in tests." The original Binet test of 1903 showed girls to be more intelligent than boys according to its measures. Binet fiddled with the test until both sexes tested equally. As Phyllis Rosser of the Center for Women Policy Studies has documented, in the early 1970s the Educational Testing Service set out to make the SAT-Verbal more "sex-neutral." Its efforts resulted in a shift of 3–10 points from girls to boys—a result that ETS considered gender neutral, though one that in fact favored boys slightly.[41]

The male advantage was achieved by increases in science and sports content in the reading-comprehension passages. On the November 1987 test 66 percent more boys than girls answered the following question correctly:

> Although the undefeated visitors ______ triumphed over their underdog opponents, the game was hardly the ______ sportswriters had predicted.
>
> A. fortunately . . . . . upset
> B. unexpectedly . . . . . classic
> C. finally . . . . . rout
> D. easily . . . . . stalemate
> E. utterly . . . . . mismatch.

Generally boys outperform girls on questions related to sports, science, or business, and on questions dealing with concrete information. Girls outperform boys on questions relating to aesthetics, philosophy, human relationships, and on questions using abstract concepts and ideas.[42]

ETS has made no comparable effort to balance the SAT-Math, on which boys outscore girls by between 41 and 52 points, or one-half of a standard deviation. The gender gap in math scores has persisted since 1967, when data on sex differences were first collected. Women's scores have not risen despite the increased number of math and science courses they now take.[43]

There is good evidence that the SAT-Math could be manipulated to decrease the current difference between boys' and girls' scores. The psychologists Elizabeth Fennema, Janet Hyde, and Susan Lamon argue that the math gap between males and females is narrowing, though this change is not reflected in SAT scores. As early as 1973 Thomas Donlon of ETS noted that the gender gap on the SAT-Math could be reduced by an increase in the number of algebra questions (on which women excel) and a decrease in the number of geometry questions (on which men score better). A study of the November 1987 SAT-Math confirmed this finding and suggested that the content of verbal problems can favor one sex over the other. Students tend to skip questions with unfamiliar content, and girls typically complete fewer problems than boys. On the 1987 test boys outscored girls by the widest margin on a question having to do with basketball team statistics. Finally, the current format of the test—timed and multiple-choice—can influence boys' and girls' performance. Girls tend to score higher on essay and open-ended questions; they also do well on contextual questions such as those asking about the amount and type of information needed to solve a problem. Girls tend to react badly to time pressure. As critics of the test have pointed out, it is not clear that emphasizing speed—requiring snap judgments rather than analysis and reflection—tests the most important aspects of intellect. Girls are also less likely than boys to risk guessing at the right answer. Girls' scores improved dramatically when testmakers removed the "I don't know" option from the NAEP, forcing girls to guess when they did not know an answer.[44]

Considering the gender bias built into it, how useful is the SAT? Its purpose is first and foremost to predict grades for the first year of college. As mentioned in Chapter 2, the SAT tends to underpredict women's grades and overpredict men's. A study of 4,000 Maryland high school students, for example, found that girls who earned higher grades than boys in pre-calculus and calculus classes scored significantly lower (37–47 points) than the boys on the SAT-Math. The ETS's own studies indicate that women do as well in college math courses as men with significantly higher scores on the math SAT. Hyde, Fennema, and Lamon also found that the SAT showed larger sex differences in math than any of the other college-admission tests. (On the NAEP, for example, in 1992 boys outperformed girls in math by only a small margin.) In light of these findings Federal District Judge John M. Walker ruled in 1989 that the SAT discriminates against girls, and prohibited the New York State Department of Education from using SAT scores as the sole basis for awarding merit scholarships. In the late 1980s MIT also took steps to counterbalance the apparent bias in the SAT by admitting students, especially girls with good math preparation, who scored under 750 on the SAT-Math.[45]

In her study of the SAT Phyllis Rosser found that largest gender disparities between test scores and academic performance occurred among boys and girls with the highest grade point averages (A-plus to A). Girls receive 5 percent more A-pluses than boys in subjects relating to verbal skills and 10 percent more A-pluses than boys in math classes. Yet these girls score significantly lower on the SAT than boys with equivalent GPAs. This means that "the highest achieving girls are penalized the most by the SAT gender gap." These girls, who on the basis of their grades might have been accepted at prestigious colleges and won distinguished scholarships, are often disqualified by their test scores. Scholarships awarded using test scores alone are twice as likely to go to boys as to girls. Low scores on standardized tests can also exclude girls early on from academic enrichment programs and accelerated courses, including programs for the "gifted and talented." Lower test scores also tend to lower women's academic aspirations as well as their perceptions of their own abilities. Women often apply to less prestigious colleges than their grades would support.[46]

One might argue that grades and aptitude tests measure different skills. Grades may evaluate a variety of qualities—neatness, diligence, ability to complete work or follow directions, improvement over time—in addition to mastery of the material. Teachers may factor in social skills such as "good citizenship." Standardized tests, in contrast, evaluate a smaller range of skills, such as analytical reasoning and the ability to work under pressure. It is not clear, however, that the latter skills are the most important for long-term success or scientific creativity. Perhaps the most telling finding in this area is that ability as measured on standardized tests is not closely related to research performance in science.[47]

In mathematics as in many other fields, few efforts have been made to study gender differences in relation to other important variables, such as ethnicity, culture, or class. If for a moment we assume that standardized tests do accurately measure a difference in mathematical ability between boys and girls in the United States, is this difference consistent across cultures and across time? Naturists, such as Camilla Benbow and Julian Stanley, argue that it is. They see the superior male mathematical abilities—quantitative and spatial abilities as well as field articulation—as hard-wired in the male brain. In order to test the fixity of gender differences in mathematical ability, Benbow and Stanley had the U.S. SAT-Math translated into German and Mandarin Chinese and administered to students in Germany and China. Their results showed the same range of sex differences in these radically different cultures, leading them to conclude that indeed "sex differences may partly be biologically induced." As biological factors, they suggest greater brain lateralization and exposure to high levels of testosterone that slow the development of the left hemisphere and thereby enhance the development of the right hemisphere (where spatial abilities are located). Whatever male achievement may be in the United States, American students—neither boys nor girls—do not do well by world standards. In 1989 U.S. thirteen-year-olds placed ninth among twelve nations in science skills.[48]

Studies of boys and girls from different ethnic groups within the United States show some surprising results. Girls in Hawaiian public schools, for example, outperform boys both in the classroom and on standardized tests, especially among Filipino, Hawaiian, and Japanese populations. Differences are found as early as the fourth grade and increase as students mature. Other studies have suggested that African-American and Hispanic high school girls test higher than boys of those ethnicities in mathematical ability. It should also be pointed out that Asian-American boys outscore European-American boys by 26 points on the SAT-Math, and that European-American boys average only 14 points higher than Asian-American girls (not considered statistically significant). The few comparative studies of mathematical ability that have been done suggest that sex differences in mathematical achievement vary by ethnicity along a continuum ranging from moderate differences favoring girls to large differences favoring boys.[49]

Class can also affect gender differences in scores on the SAT-Math. It has long been known that the SAT test scores correlate highly with family income and tend to reflect class and educational advantages. But the correlation between class standing and test scores is highest for boys. Girls at every income level score lower than boys with comparable family incomes.[50]

It is generally assumed that high mathematical ability is crucial for success or even interest in science. Indeed, as the math content of a science increases, the number of women in that science decreases. Although facility in mathematics is undoubtedly necessary for most scientific fields, the direct relationship between mathematical ability and success in science has yet to be explored.[51] A U.S. Department of Education study showed that when math scores were the same, nearly twice as many men as women pursued physics. It is not, then, only a lack of ability that is keeping women out of science; something else is producing the disparities in men's and women's participation in academic mathematics.

The question of gender in the content of physics and math is complicated and requires further investigation. This is a task for the best physicists, philosophers, and historians of science with rigorous training in gender studies of science. Physics has been insulated from gender critiques partly because so few people are trained to undertake them. Members of a new generation of physicists, however, either have training in gender studies or are actively seeking to collaborate with those who do.

Empirical study may reveal that gender does not permeate the most abstract level of human endeavor. It does not necessarily follow, however (as some would have it), that the feminist enterprise stands or falls on finding such examples. What has been demonstrated is that gender abounds in the cultures of math and physics, determining to a certain extent who gets educated, gets funded, enjoys prestige, and can build upon opportunities. The content of physics is not distinct from its cultures; cultures—shared beliefs, expectations, "taken-for-granteds," and material well-being—mold many aspects of the various sciences. The greatest physicists have been those who have asked the right questions. Newton asked why the moon fell (when everyone else assumed it did not); Einstein asked what the world would look like if you rode along with a beam of light.[52] Ultimately, the culture of physics sets conditions for who has the training and the opportunity to ask questions. Feminism has made significant contributions by asking new questions, questions that often stand at odds with the foundational assumptions in a discipline. It remains

to be seen what these questions may be in the fields of physics and math. Getting the right answers—turning the crank— may be gender free. But it is often in setting priorities about what will and what will not be known that gender has an impact on science. It is also perhaps here that the greatest feminist contributions will be made.